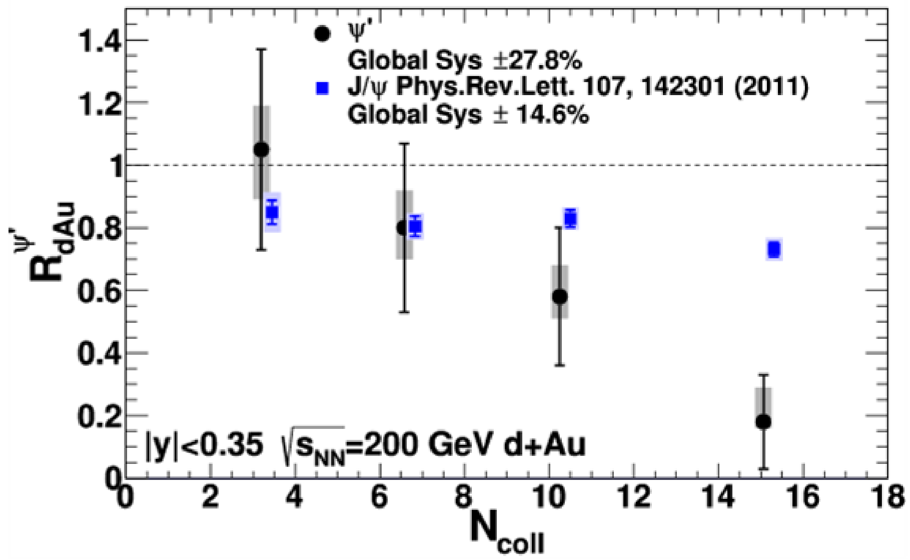
Quarkonia in pp and pA collisions with ATLAS

Miguel Arratia
Cavendish Laboratory, University of Cambridge

High pT Physics in the RHIC-LHC Era @ BNL

Motivation

Phys.Rev.Lett. 111 (2013)



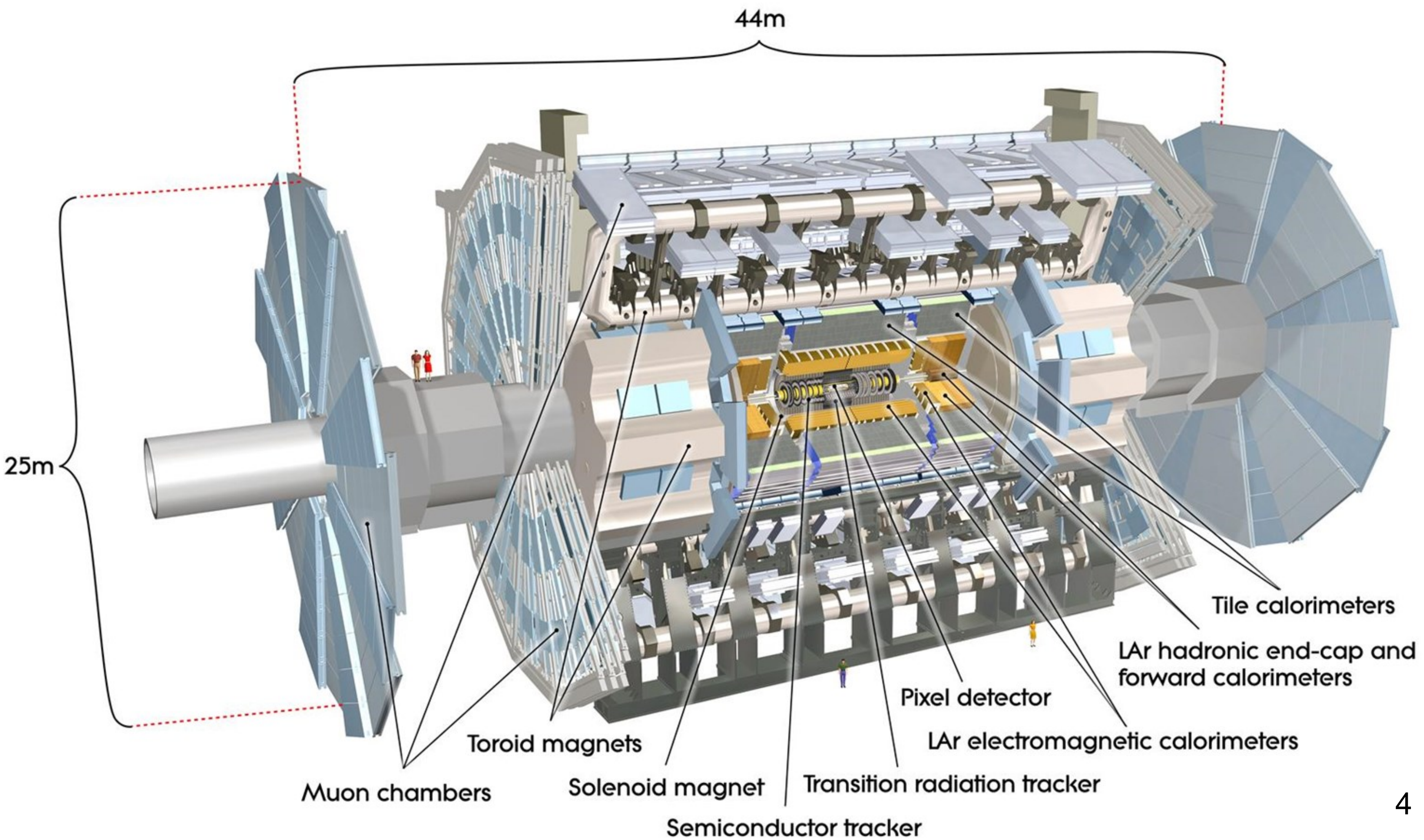
- Essential for even a qualitative understanding of AA collisions
- But quarkonia in pA interesting in its own right, as it probes QCD in medium
- Recent pA $\psi(2S)$ results challenge explanations in terms of initial state nuclear breakup, gluon shadowing and energy loss.

Outline

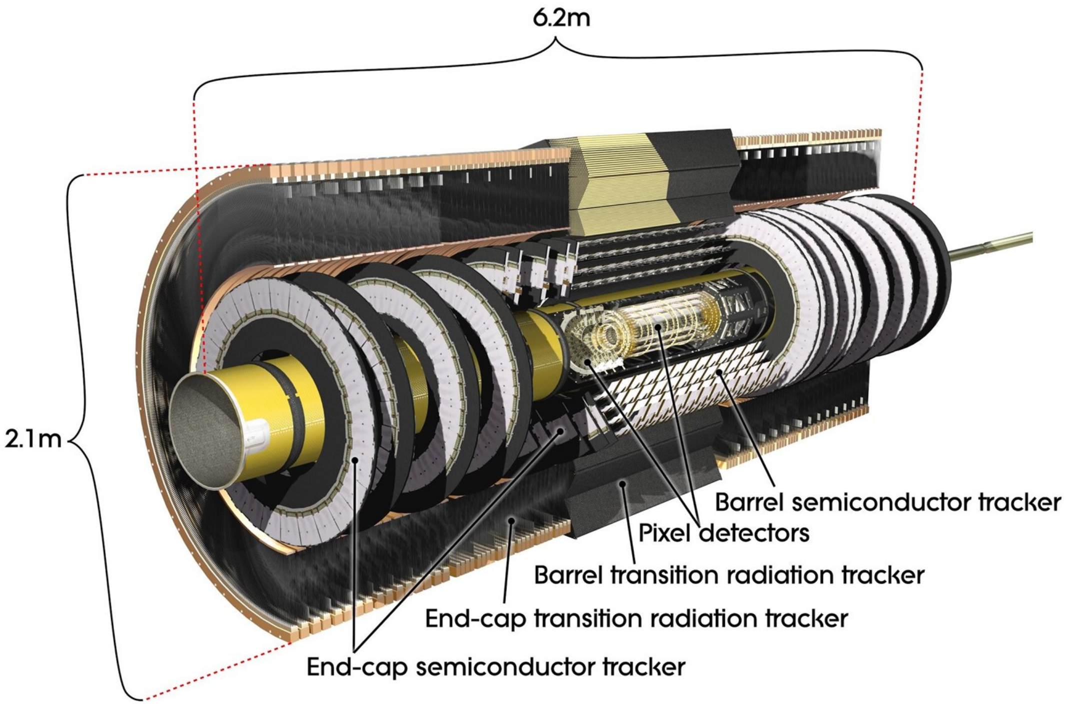
J/ψ in 5 TeV pPb

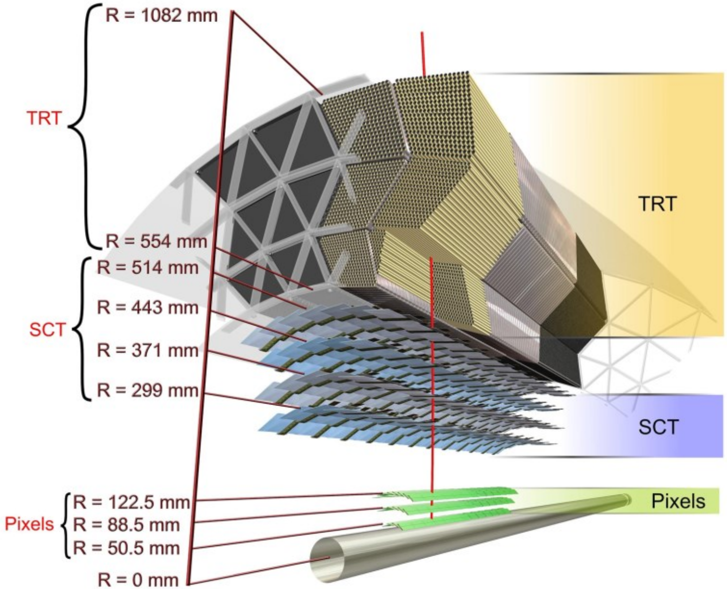
J/ψ and $\psi(2\mathrm{S})$ in 5 TeV pPb and 2.76 pp

$\Upsilon(\mathrm{nS})$ in 5 TeV pPb and 2.76 pp


44m
25m
Tile calorimeters
LAr hadronic end-cap and forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Muon chambers
Solenoid magnet
Transition radiation tracker
Semiconductor tracker

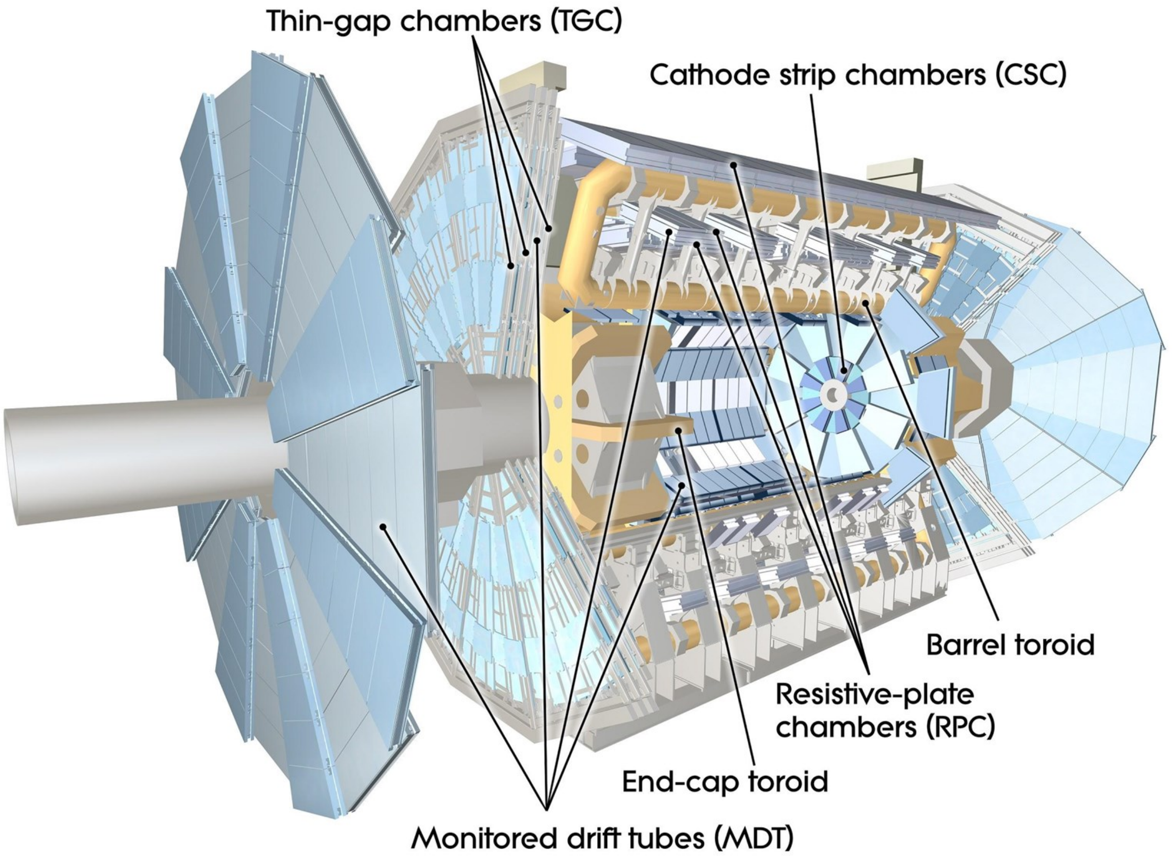
Inner detector





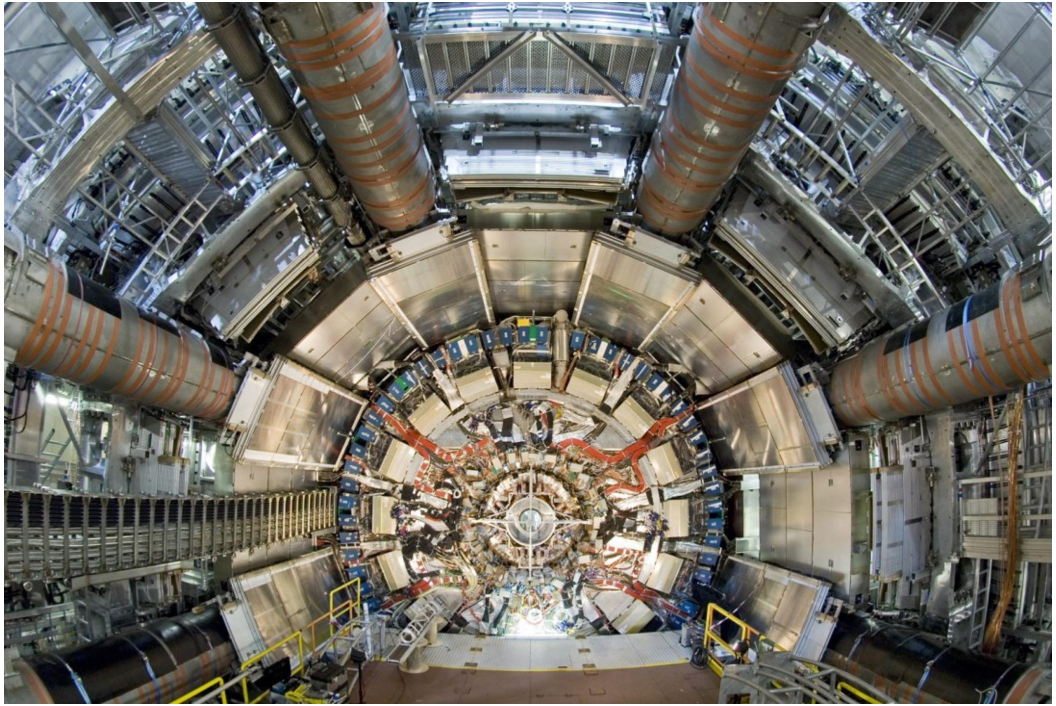
- Pixel and microstrip detectors provide resolution to measure $b\bar{b} \longrightarrow J/\psi + X$

Muon Spectrometer



- Multiple layers of tracking and trigger chambers that cover $|\eta| < 2.4$
- Momentum measurement with bending from azimuthal magnetic field.
- Standalone operation (can do tracking, vertexing without inner detector)

Calorimeter system and its impact on this measurement



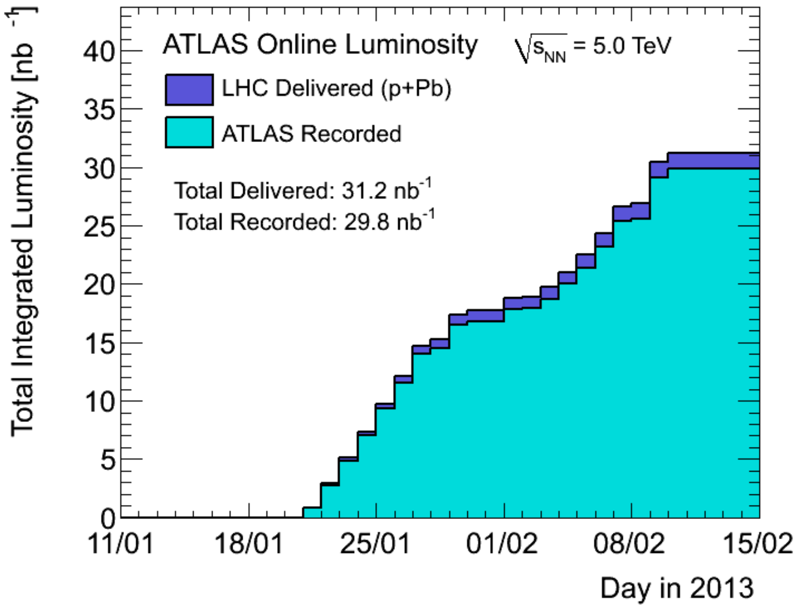
- Muons loose about 3 GeV of energy before getting to muon spectrometer

Cons : Cannot measure low pT muons, limiting acceptance for charmonium states

***Pros* :** Hermeticity of calorimeter reduces the background from hadrons

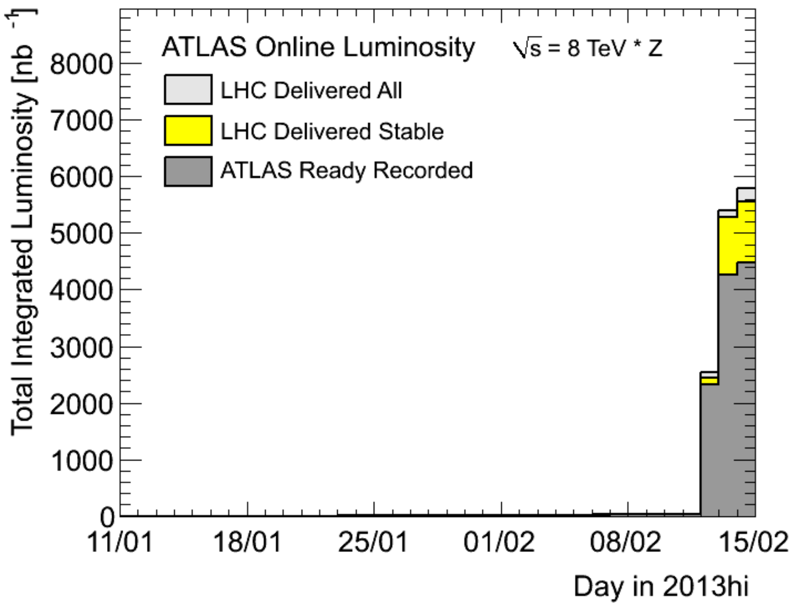
Datasets

p-Pb @ 5 TeV



$$28.1\ \mathrm{nb}^{-1} \pm 2.7\%$$

pp @ 2.76 TeV

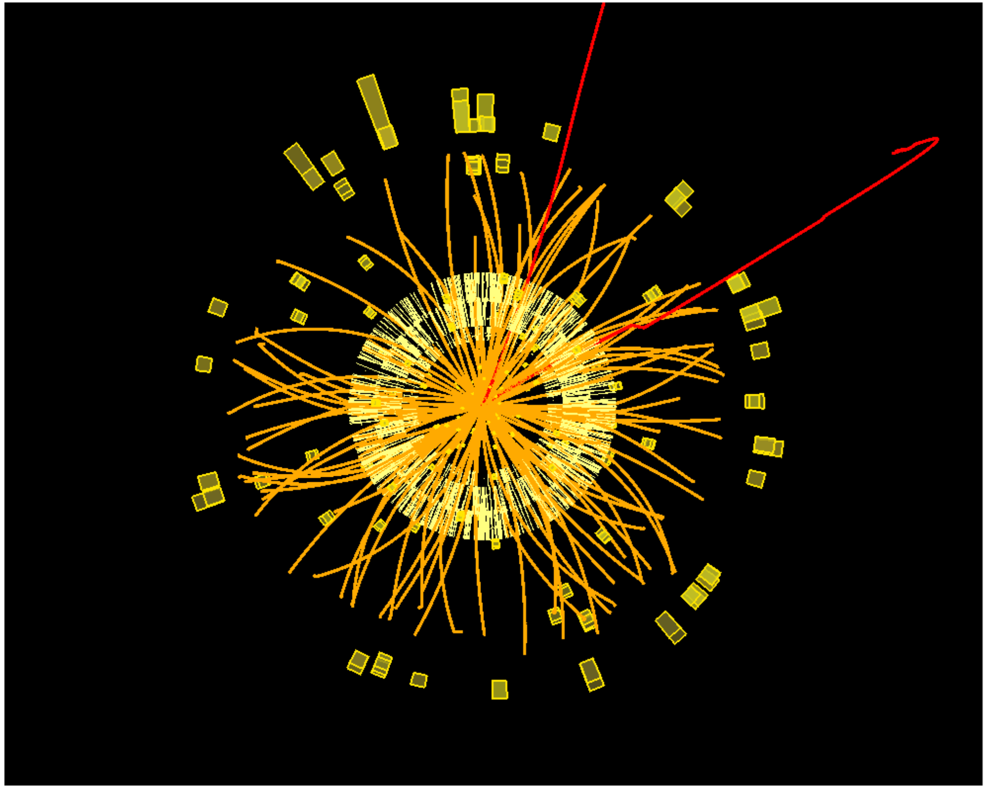


$$3.9\ \mathrm{pb}^{-1} \pm 3.1\%$$

Event selection

- Dimuon trigger, requires $p_{\mathrm{T}} > 2\ \mathrm{GeV}$ for each one. Full event reconstruction at software level

- For analysis we select muons with $p_{\mathrm{T}} > 4\ \mathrm{GeV},\ |\eta| < 2.4$



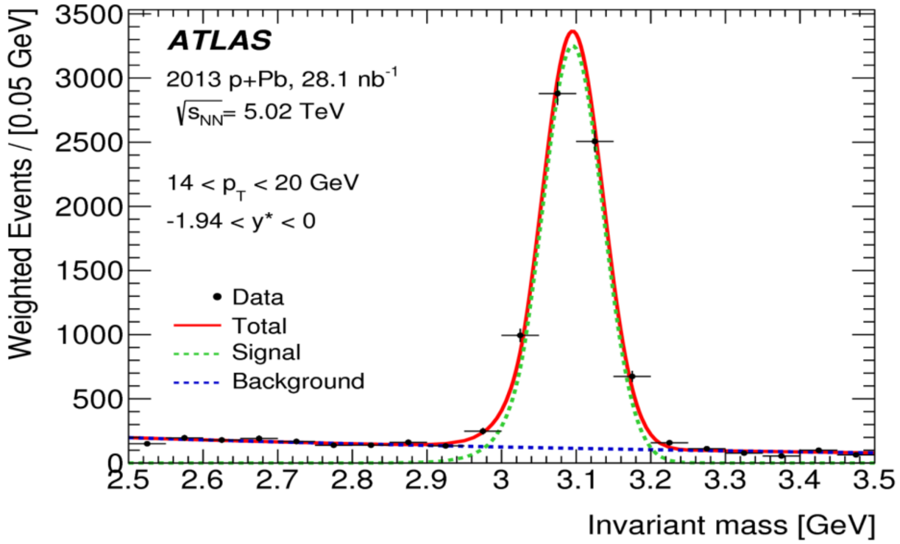
Measurement of differential J/ψ production cross sections and forward-backward ratios in p + Pb collisions with the ATLAS detector

ATLAS Collaboration (Georges Aad (Marseille, CPPM) *et al.*) Mostrar todos los 2810 autores

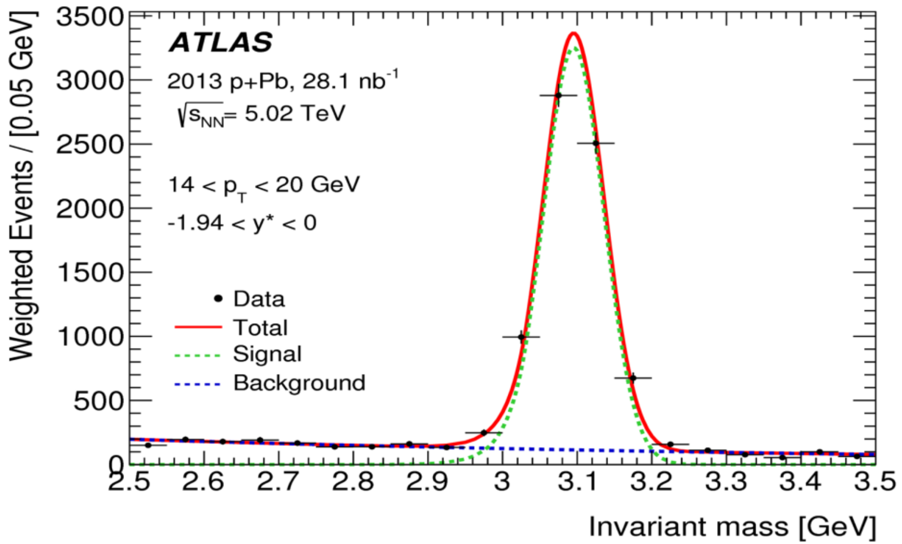
May 29, 2015 - 23 pages

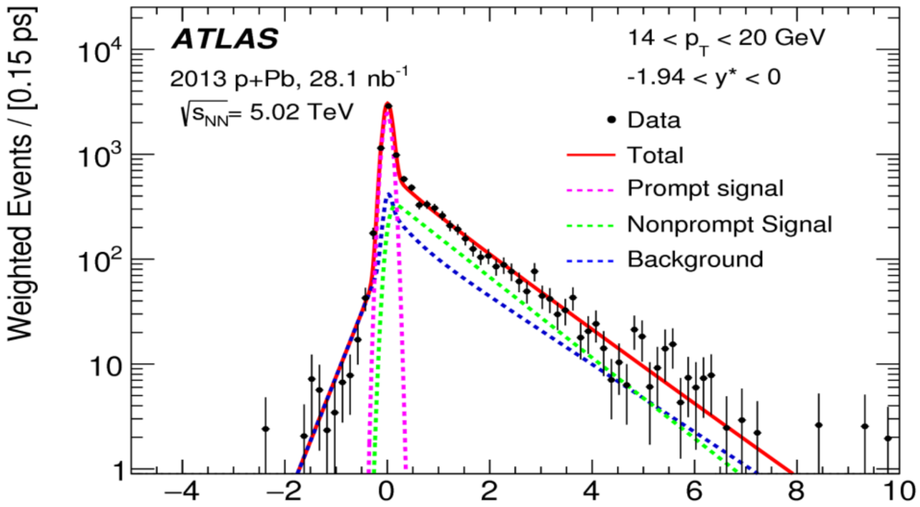
Phys.Rev. C92 (2015) no.3, 034904

J/ψ



2D fit to mass and pseudo-lifetime



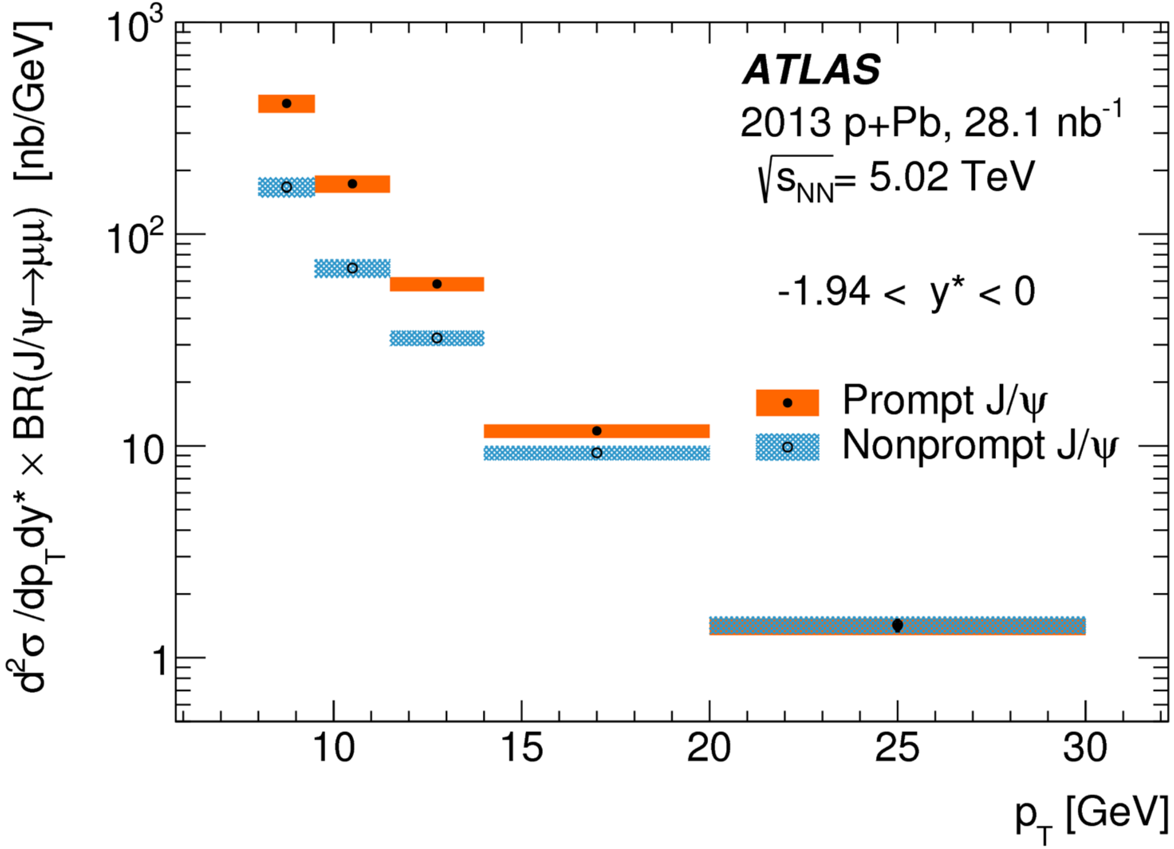


$$\tau = L_{xy} \frac{m_{J/\psi}}{p_T}$$

- Maximum likelihood fit to extract yields and fraction from b-hadron decays

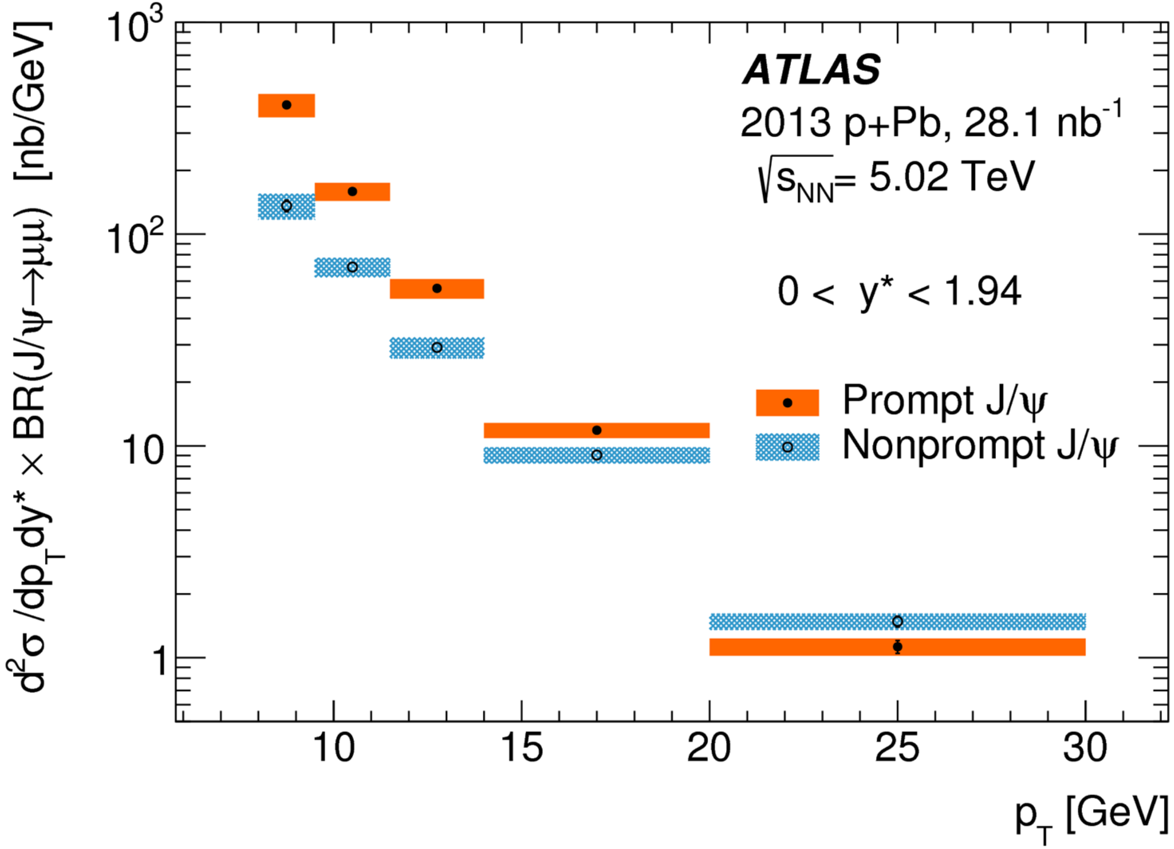
- Event-by-event weighting for acceptance, reconstruction, and trigger efficiencies $w_{\text{total}}^{-1} = A \cdot \varepsilon_{\text{reco}} \cdot \varepsilon_{\text{trig}}$

Differential cross-section , ion going side



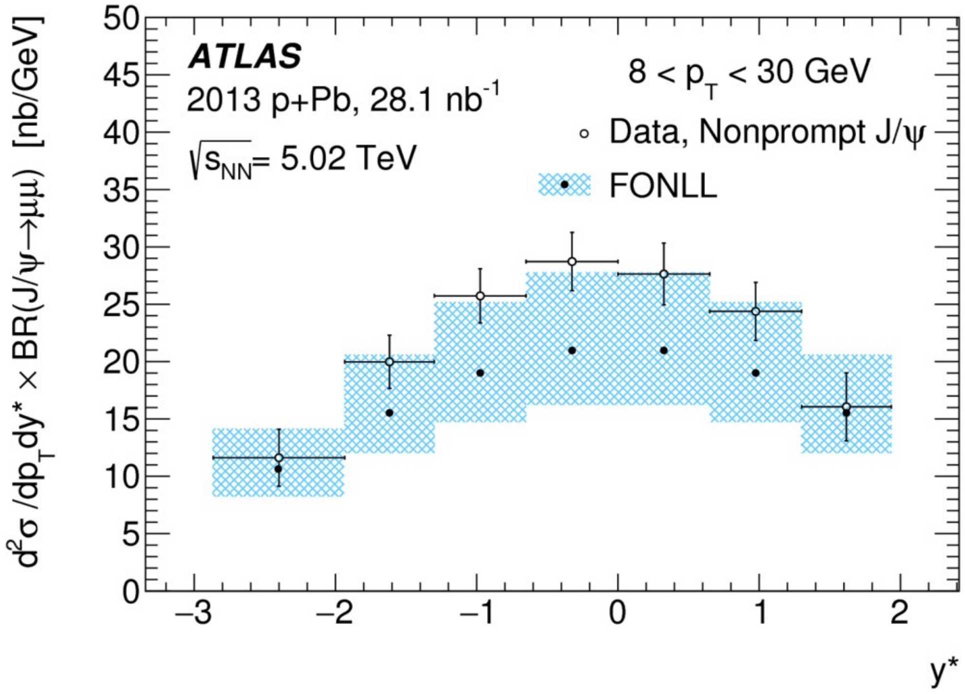
Prompt J/ψ drops faster

Differential cross-section , proton going side



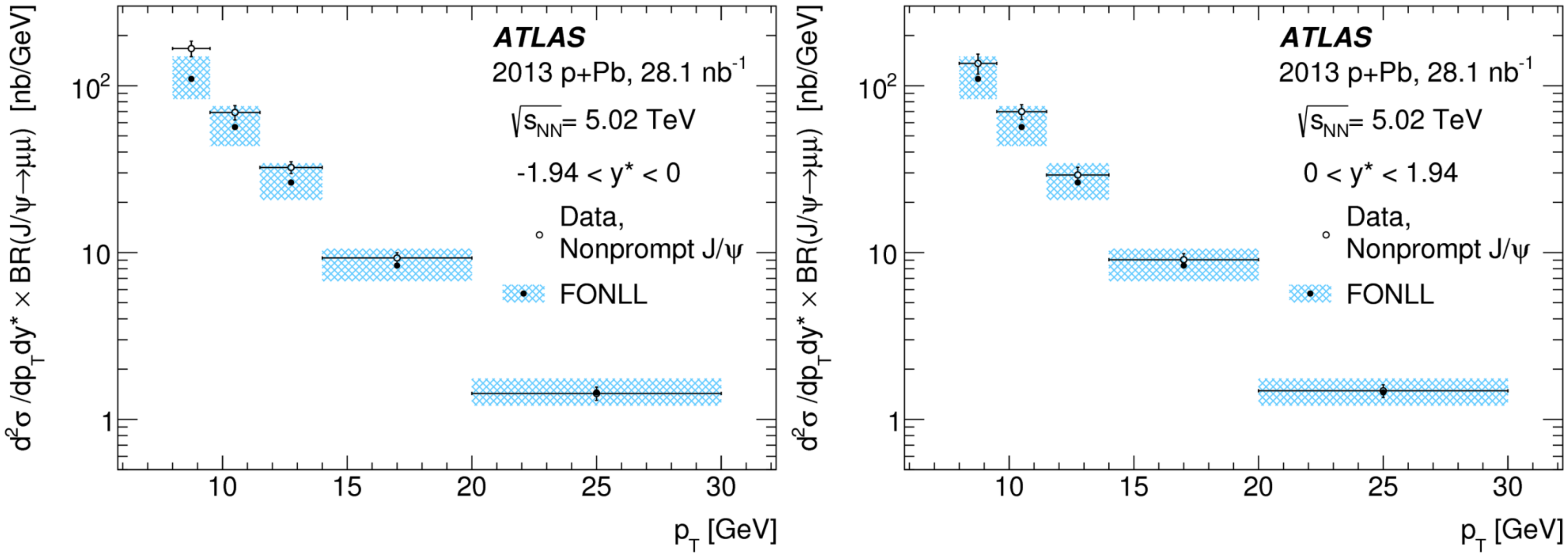
Prompt J/ψ drops faster

J/ψ from b-hadrons compared with theory



Reasonable agreement with FONLL calculation of $b\bar{b} \rightarrow \ J/\psi + X$
(without nuclear effects), but theory errors are large.

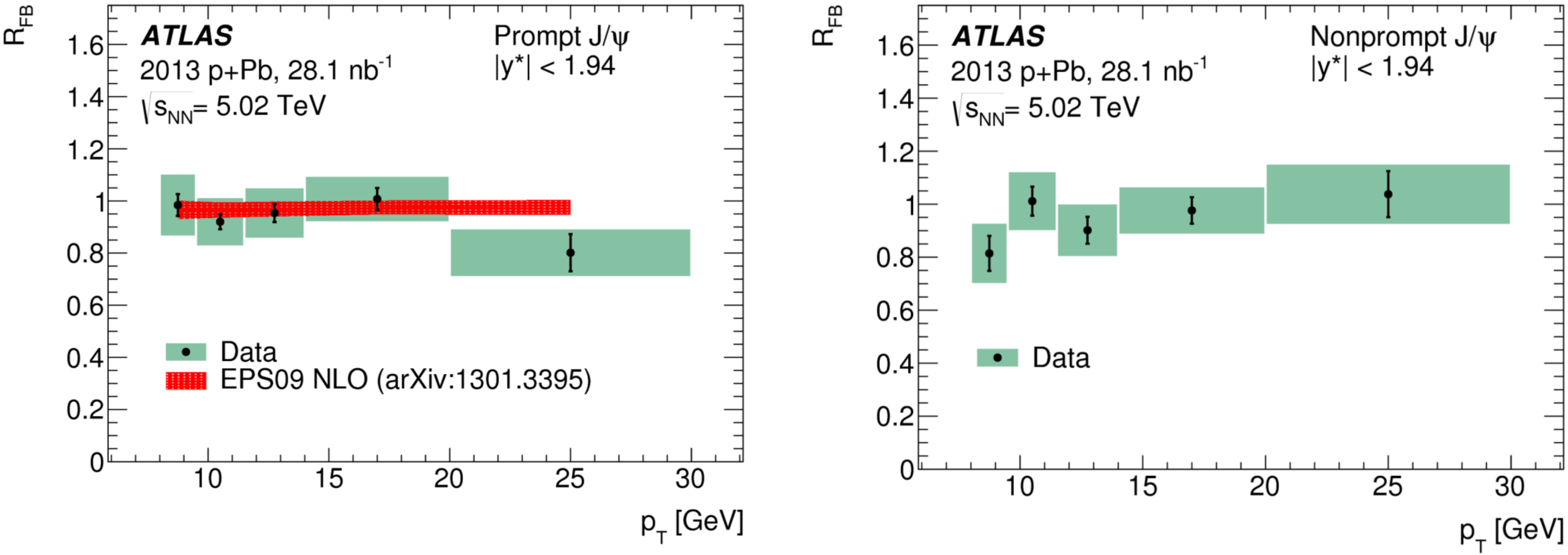
J/ψ from b-hadrons compared with theory



Reasonable agreement with FONLL calculation of $b\bar{b} \to J/\psi + X$ (without nuclear effects), but theory errors are large.

Forward-to-backward ratio

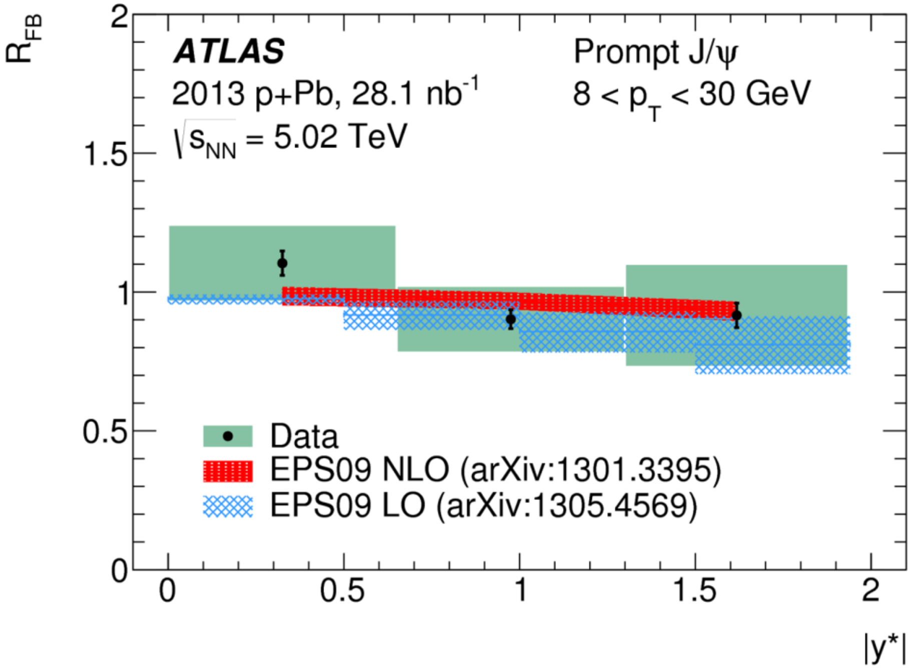
$$R_{\mathrm{FB}}(p_{\mathrm{T}}, y^*) \equiv \frac{d^2\sigma(p_{\mathrm{T}}, y^* > 0)/dp_{\mathrm{T}}dy^*}{d^2\sigma(p_{\mathrm{T}}, y^* < 0)/dp_{\mathrm{T}}dy^*}$$

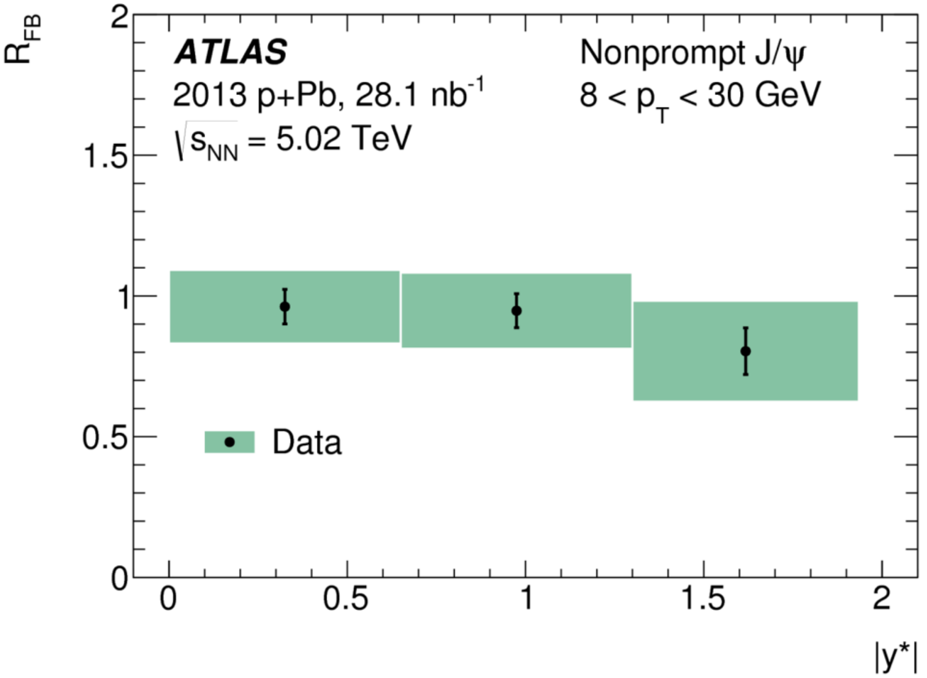


- Consistent with unity within uncertainties in both cases
- Consistent with expectations from calculations that include shadowing

Forward-to-backward ratio

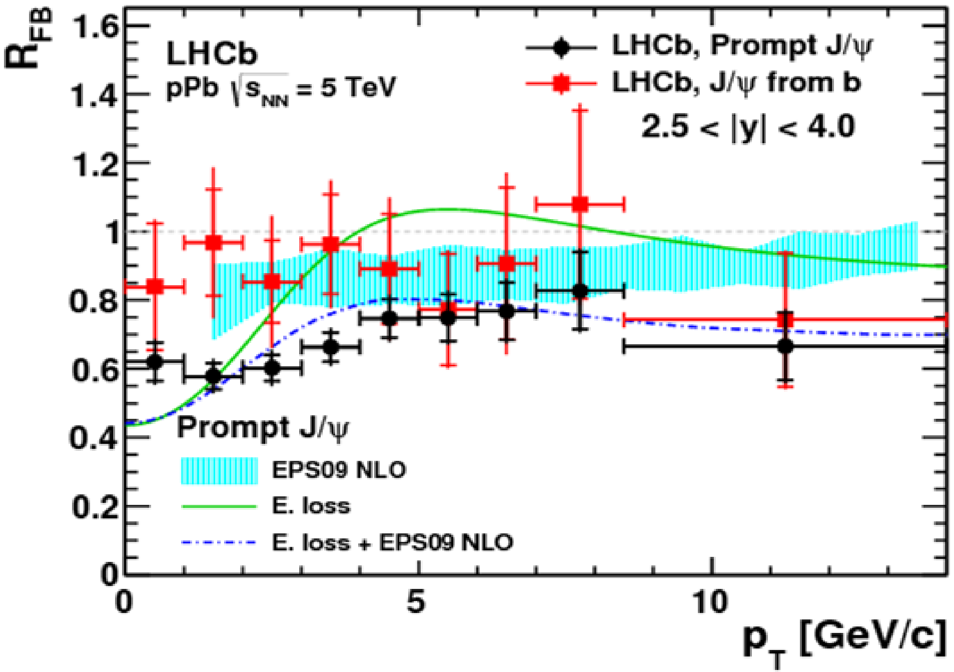
$$R_{\mathrm{FB}}(p_{\mathrm{T}}, y^*) \equiv \frac{d^2\sigma(p_{\mathrm{T}}, y^* > 0)/dp_{\mathrm{T}}dy^*}{d^2\sigma(p_{\mathrm{T}}, y^* < 0)/dp_{\mathrm{T}}dy^*}$$

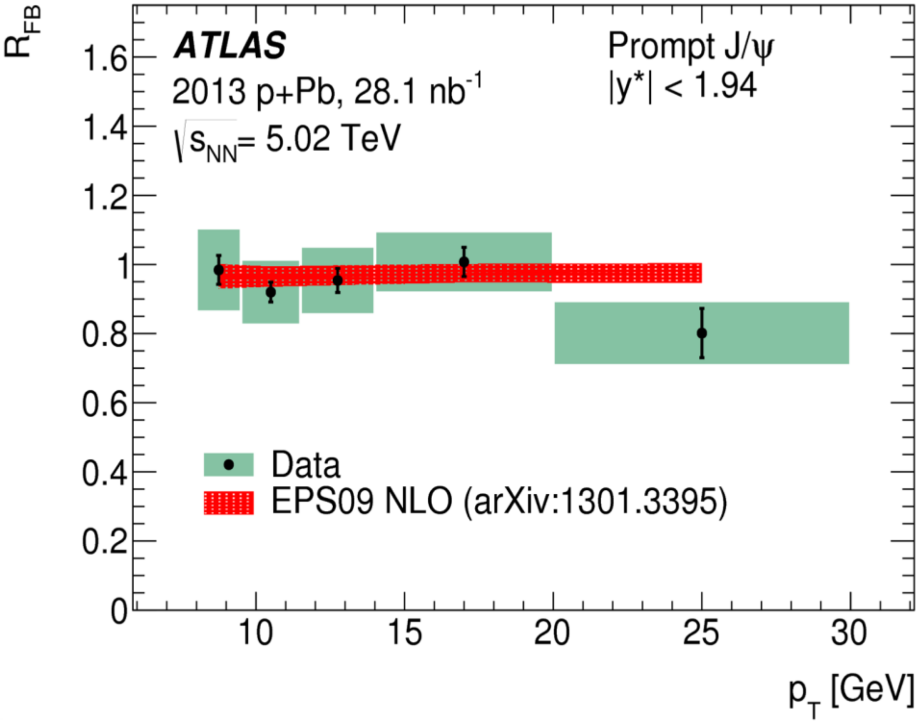




- Consistent with unity within uncertainties in both cases
- Consistent with expectations from calculations that include shadowing

Comparison with LHCb





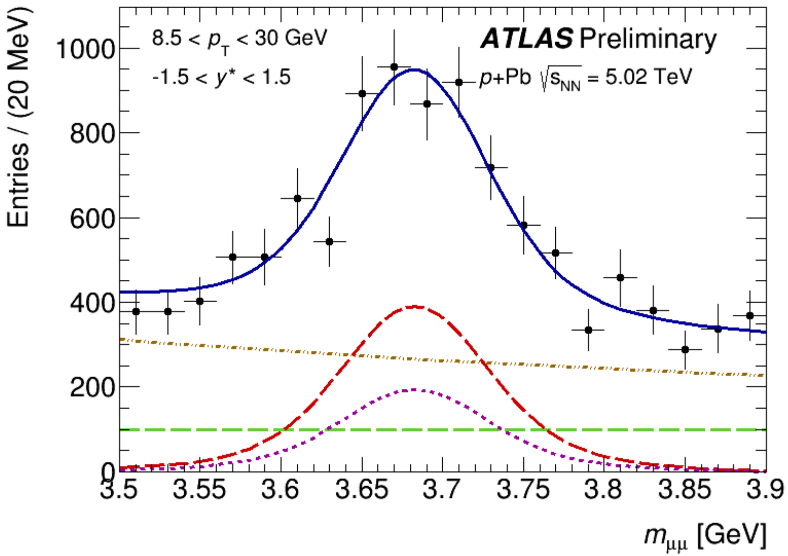
- Combined data suggest strong kinematic dependence of nuclear effects

ATLAS NOTE

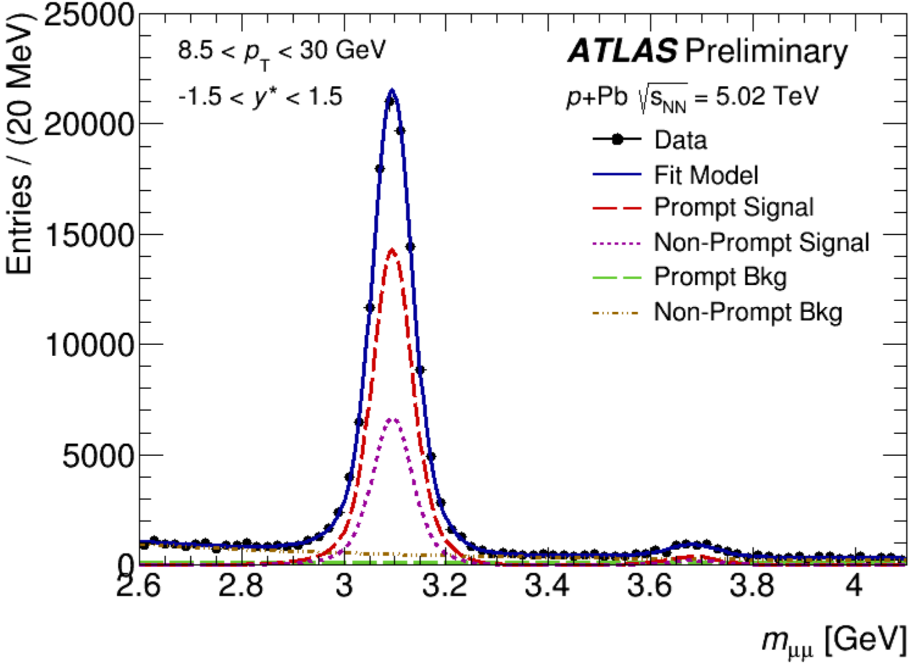
ATLAS-CONF-2015-023

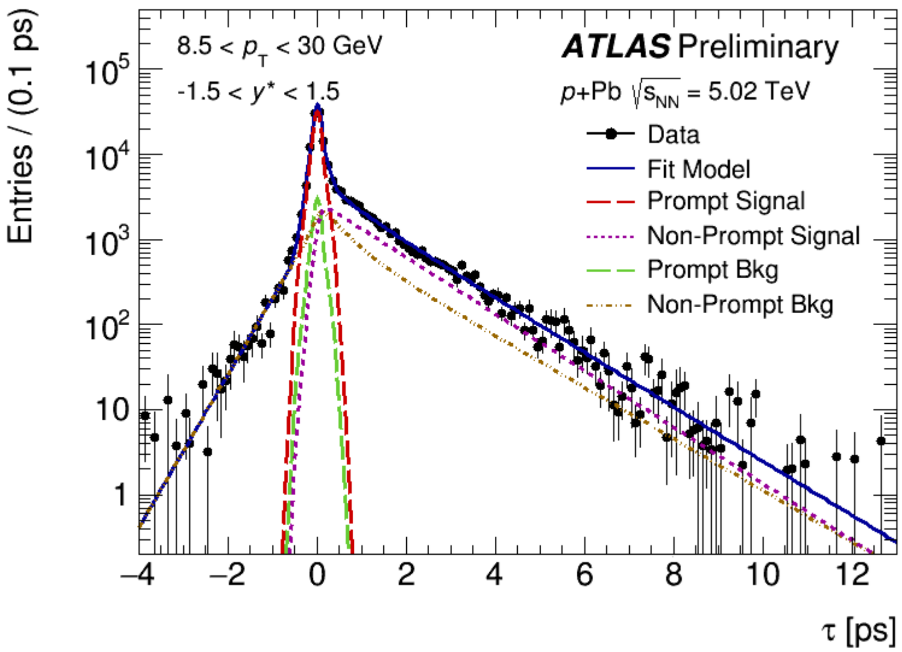
Study of J/ψ and $\psi(2S)$ production in $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV p+Pb and $\sqrt{s} = 2.76$ TeV pp collisions with the ATLAS detector

$$\psi(2S)$$



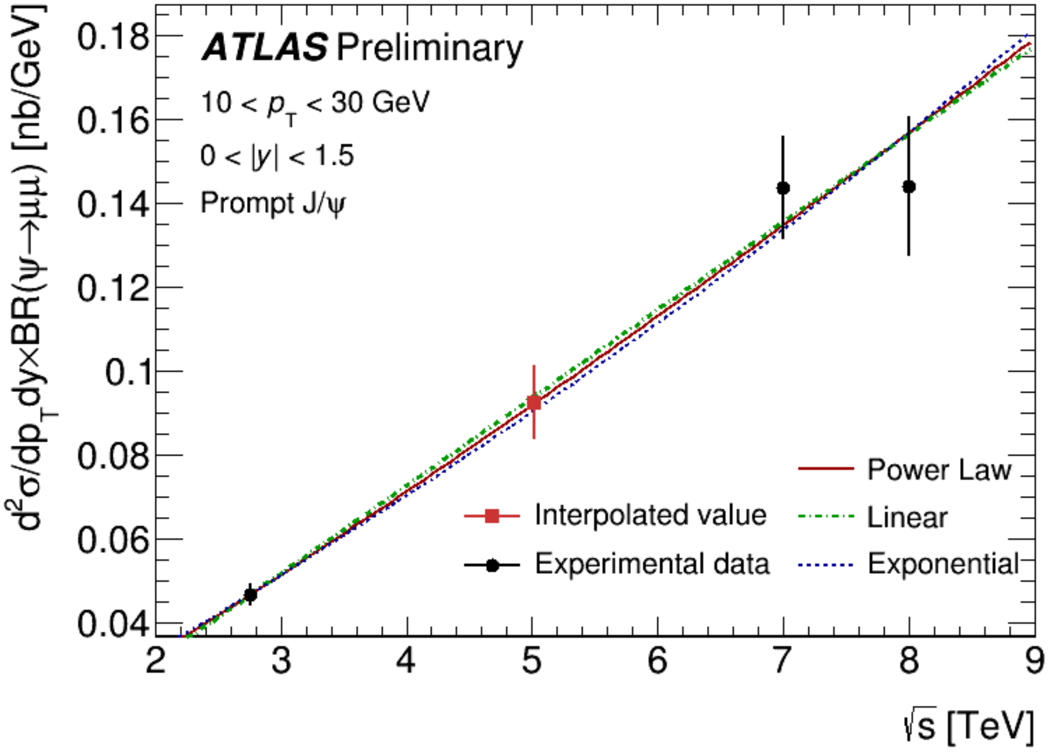
Signal extraction, p-Pb @5 TeV





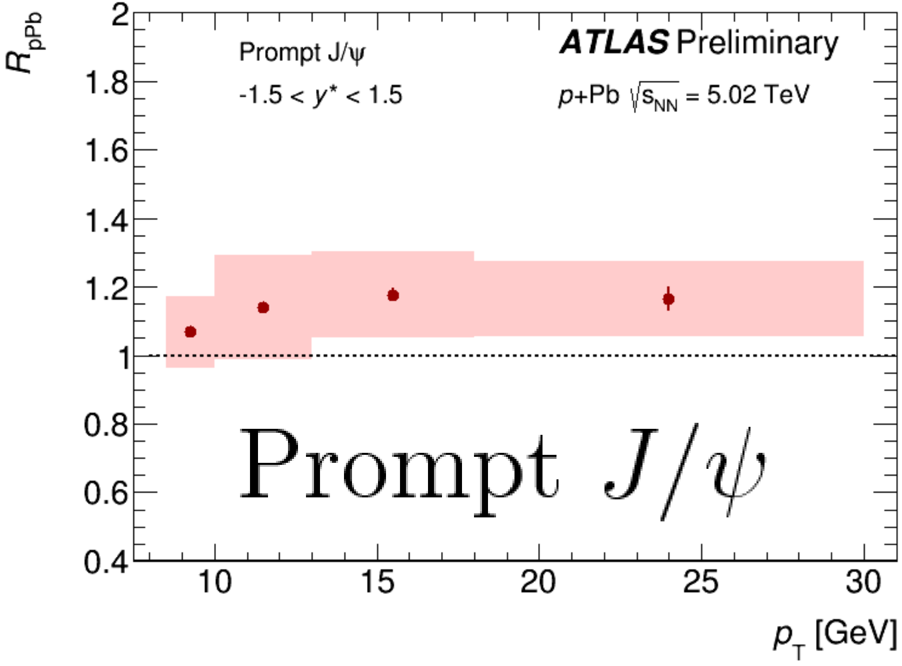
- More sophisticated fit model , but idea is the same as previous analysis
- Get fraction from b-decay in both psi(2s) and J/psi case

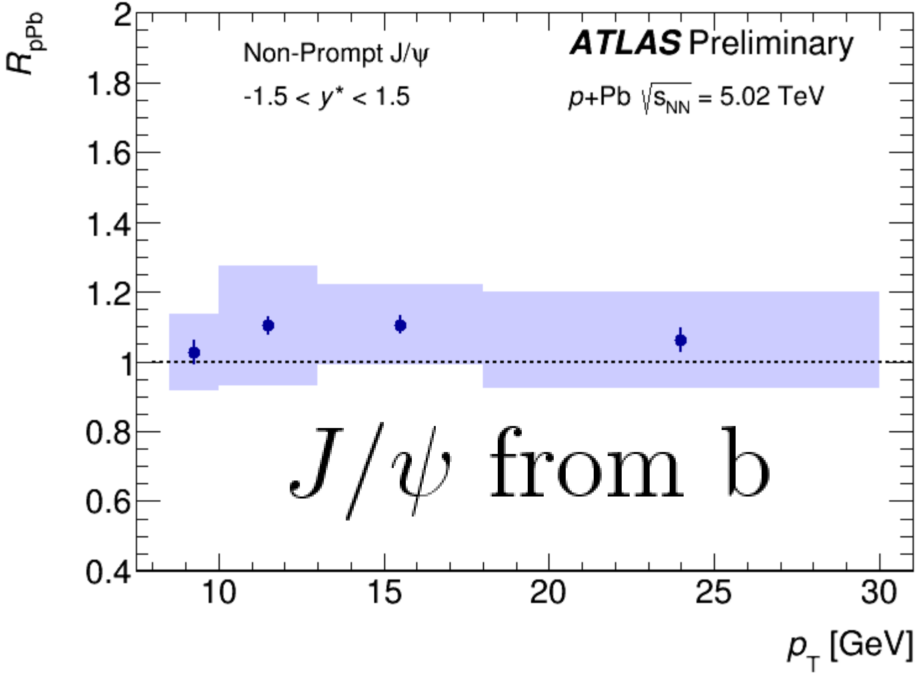
Interpolation to get pp reference at 5.02 TeV



Interpolation performed bin-by-bin

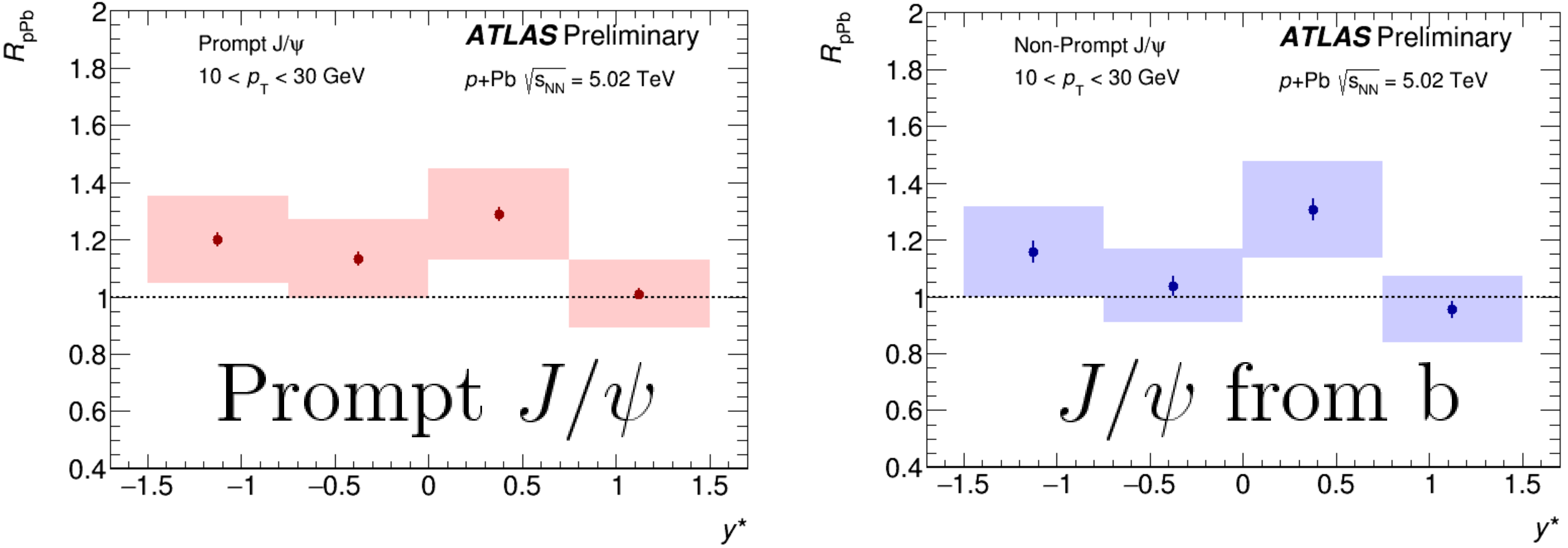
$$R_{p\mathrm{Pb}} = \frac{1}{A^{\mathrm{Pb}}} \frac{d^2\sigma_{\psi}^{p+\mathrm{Pb}}/dy^* dp_{\mathrm{T}}}{d^2\sigma_{\psi}^{pp}/dy\,dp_{\mathrm{T}}}$$





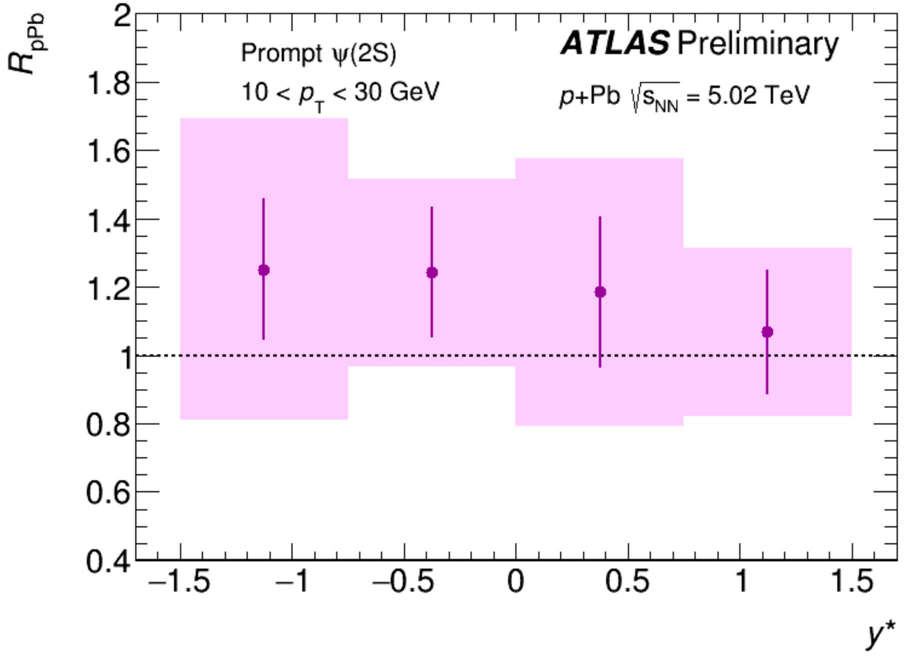
No strong pT dependence in either case

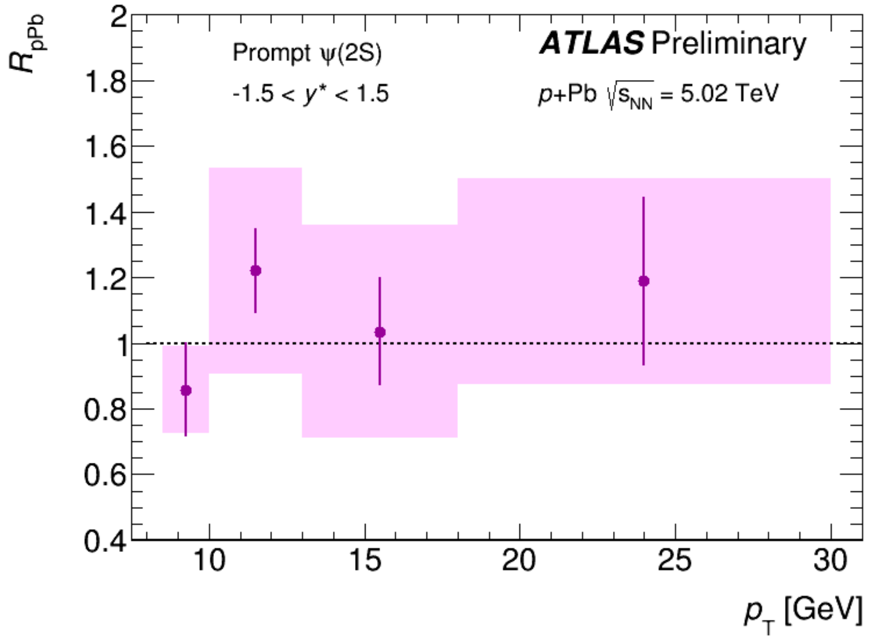
$$R_{p\mathrm{Pb}} = \frac{1}{A^{\mathrm{Pb}}} \frac{d^2\sigma_{\psi}^{p+\mathrm{Pb}}/dy^* dp_{\mathrm{T}}}{d^2\sigma_{\psi}^{pp}/dy\, dp_{\mathrm{T}}}$$



No strong rapidity dependence in either case

Prompt $\psi(2S)$ $$R_{p\mathrm{Pb}} = \frac{1}{A^{\mathrm{Pb}}} \frac{d^2\sigma_{\psi}^{p+\mathrm{Pb}}/dy^* dp_{\mathrm{T}}}{d^2\sigma_{\psi}^{pp}/dy dp_{\mathrm{T}}}$$

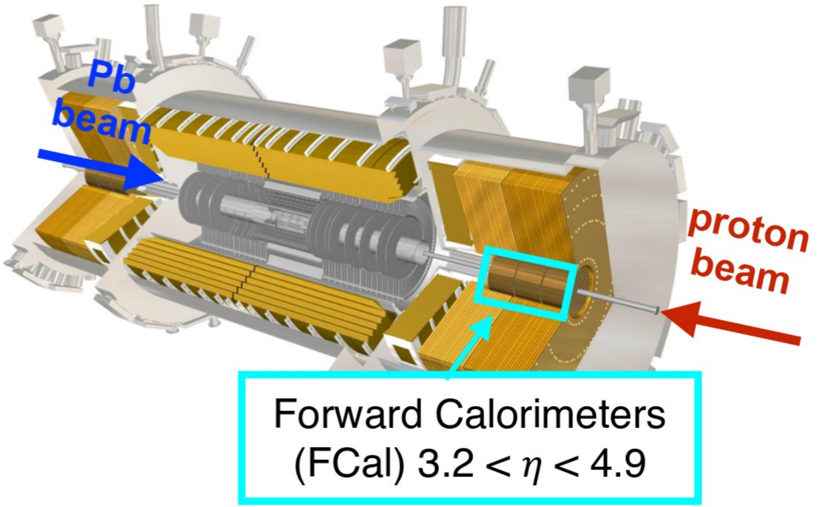


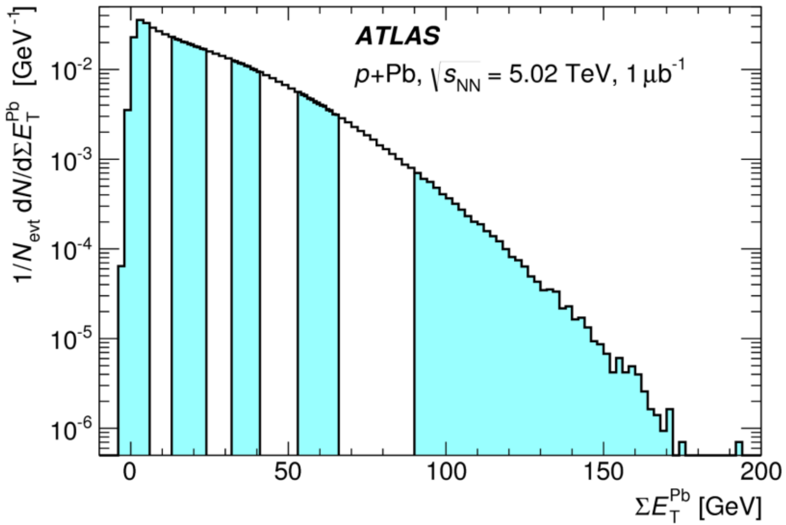


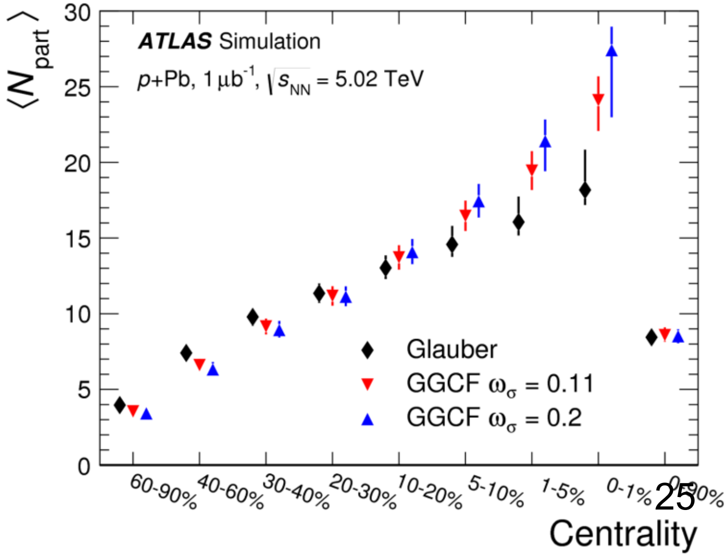
Consistent with unity, no strong kinematic dependence

Centrality determination

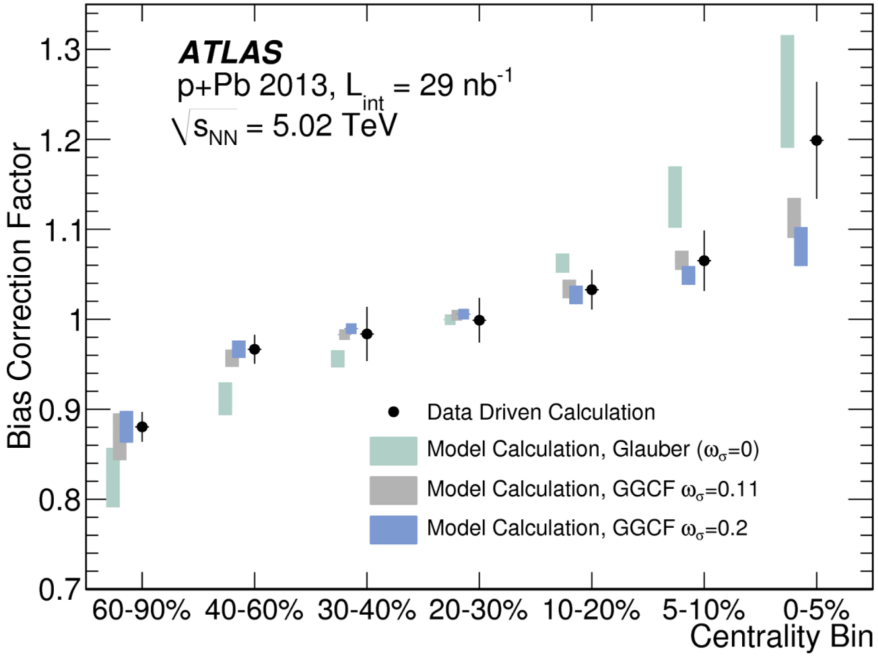
- Uses forward calorimeters in Pb going side
- Glauber model, and extensions used to determine mean number of participants
- Analysis assumes no correlation between hard scattering and soft underlying activity







Centrality bias correction

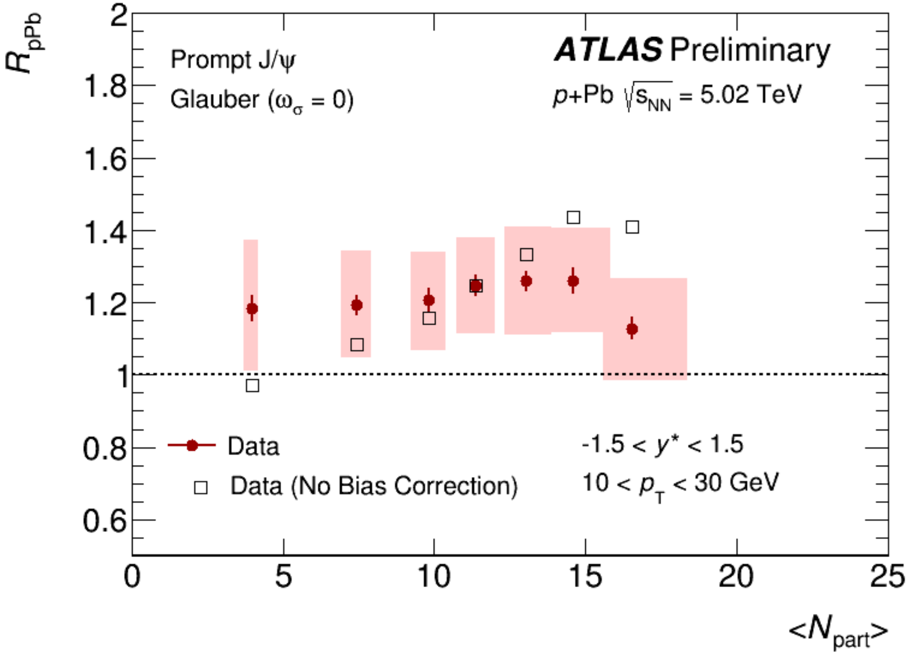


Phys. Rev. C 92, 044915 (2015)

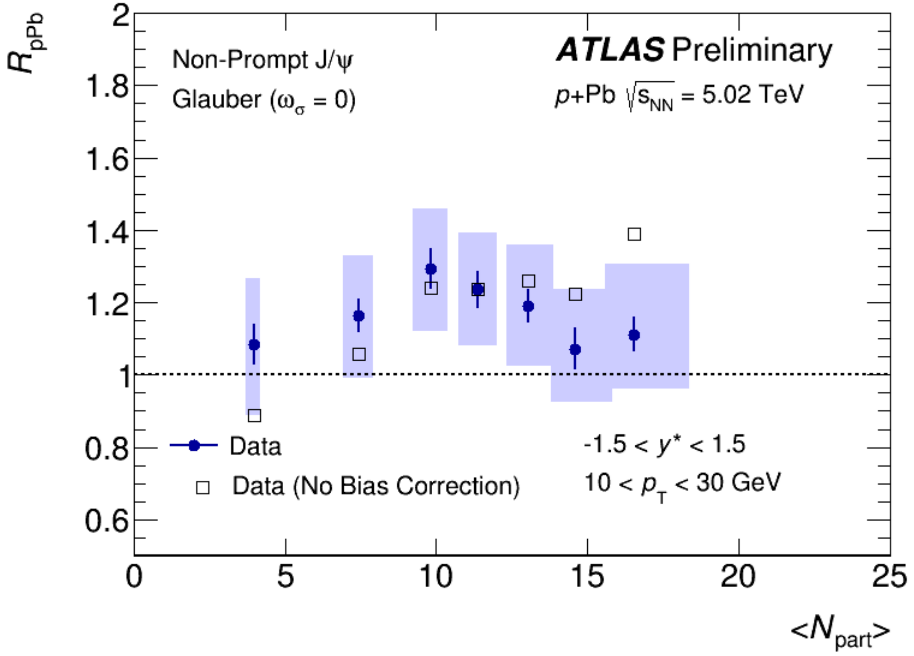
- Estimate of impact of correlation between hard scattering and soft underlying event from model [arXiv:1412.0976] and data.

$$R_{p\mathrm{Pb}} = \frac{1}{\langle T_{p\mathrm{Pb}} \rangle_{\mathrm{cent}}} \frac{1/N_{\mathrm{evt}}\, d^2 N_{\psi}^{p+\mathrm{Pb}}/dy^* dp_{\mathrm{T}} \Big|_{\mathrm{cent}}}{d^2\sigma_{\psi}^{pp}/dy\, dp_{\mathrm{T}}}$$

Prompt J/ψ



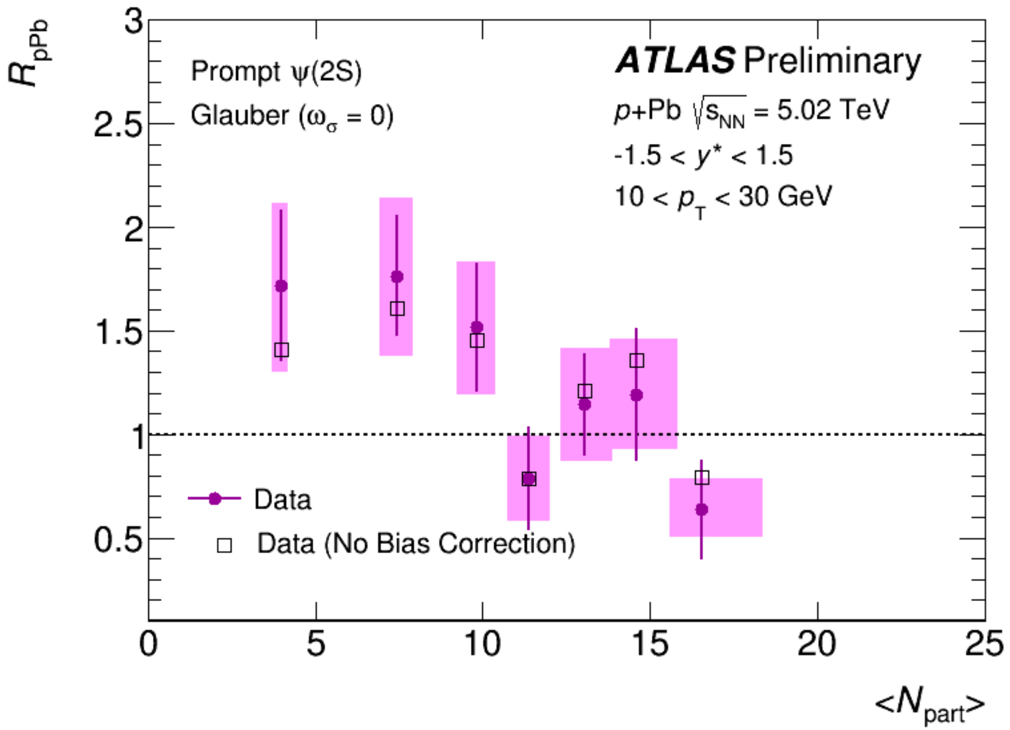
J/ψ from b



After centrality bias correction, ratio is flat

$\psi(2S)$

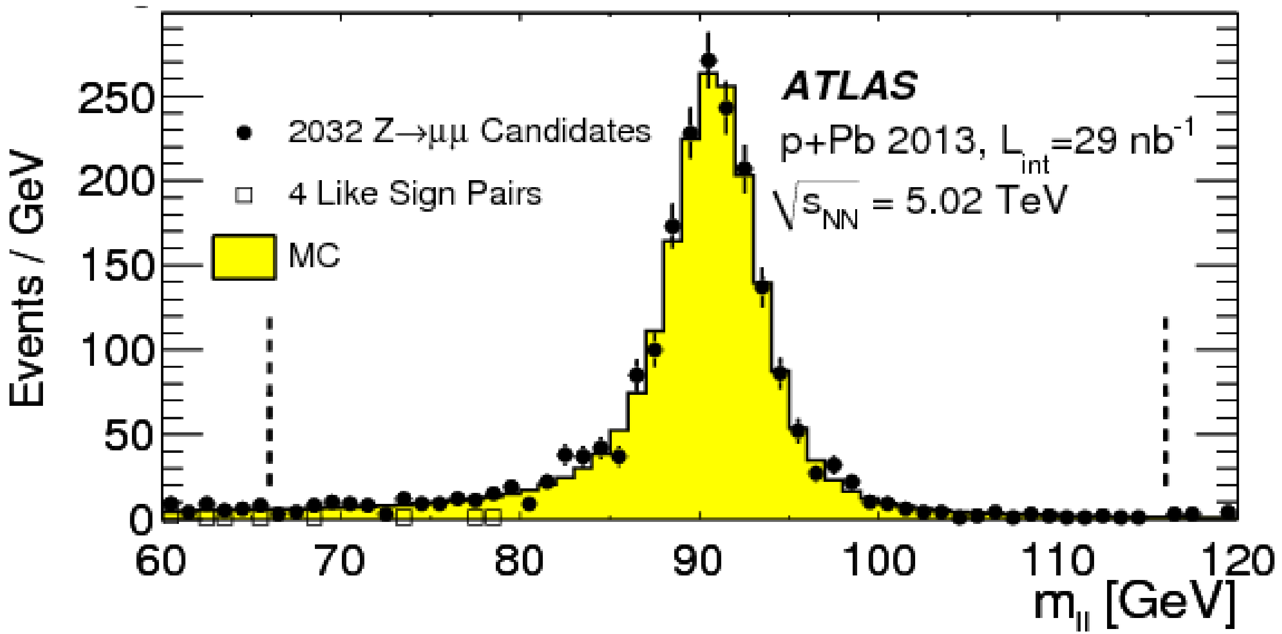
$$R_{p\mathrm{Pb}} = \frac{1}{\langle T_{p\mathrm{Pb}}\rangle_{\mathrm{cent}}} \frac{1/N_{\mathrm{evt}}\, d^2N_{\psi}^{p+\mathrm{Pb}}/dy^*dp_{\mathrm{T}}\big|_{\mathrm{cent}}}{d^2\sigma_{\psi}^{pp}/dydp_{\mathrm{T}}}$$



Hint of centrality dependence

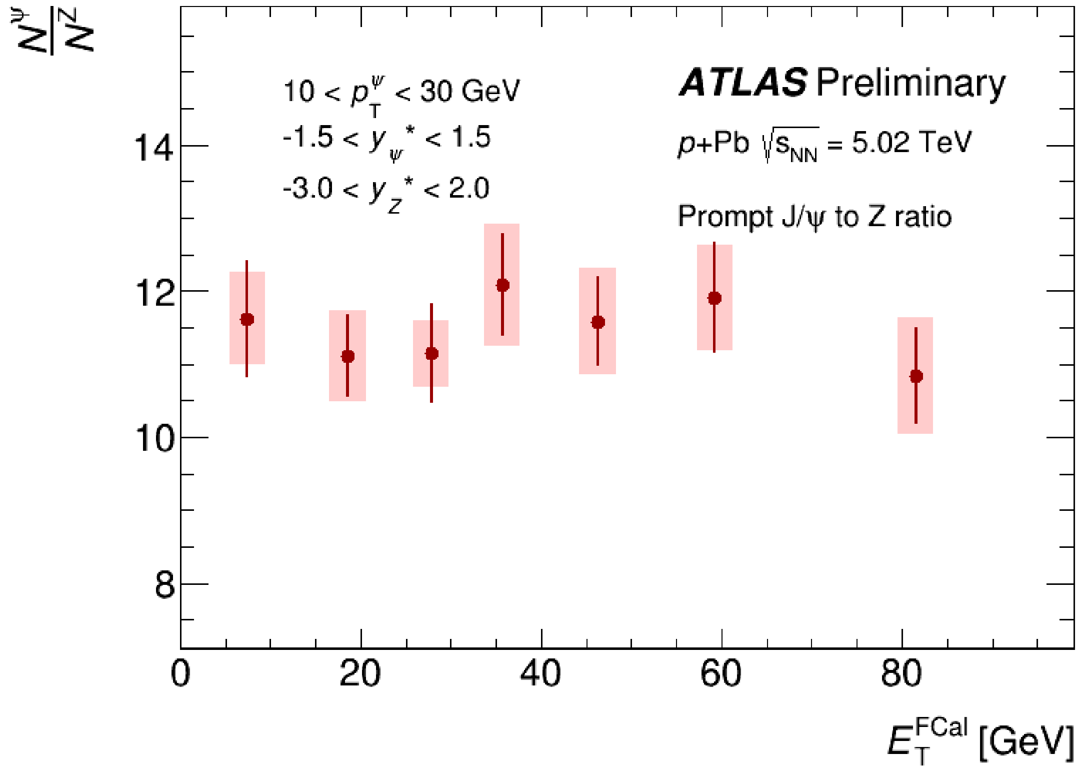
Standard candle: the Z boson

Phys. Rev. C 92, 044915 (2015)



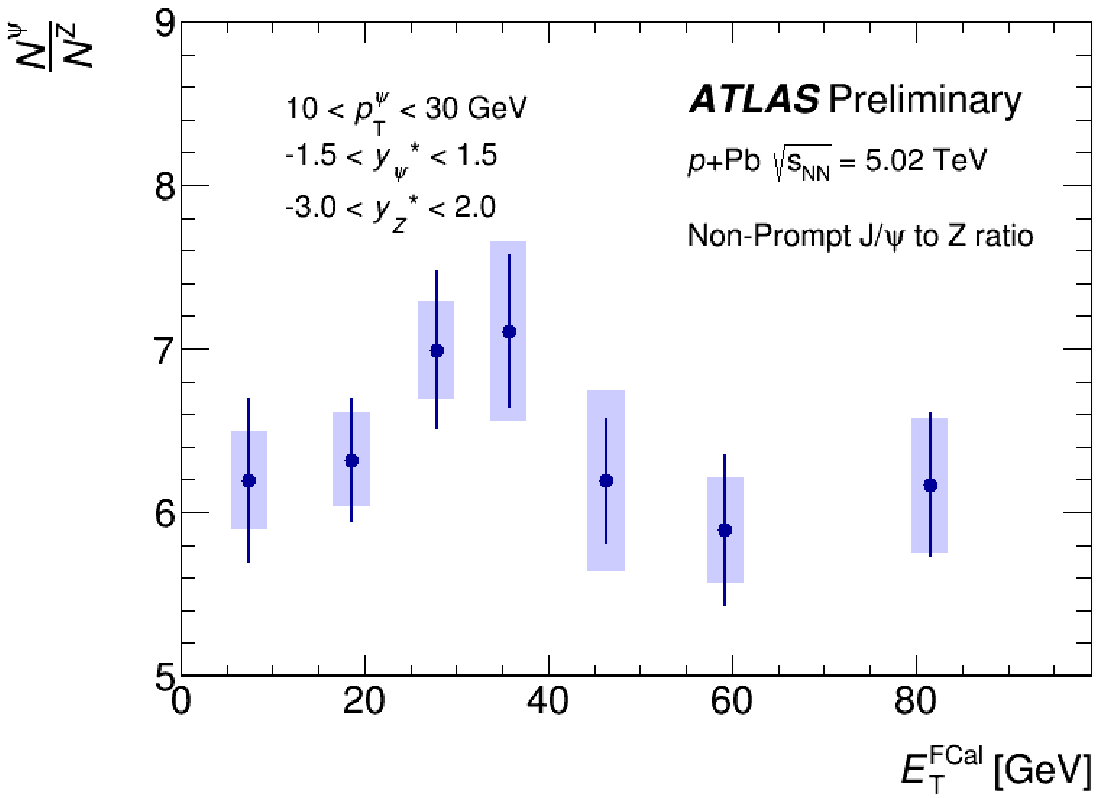
Use Z as a model independent reference of centrality

Prompt J/ψ to Z ratio vs multiplicity



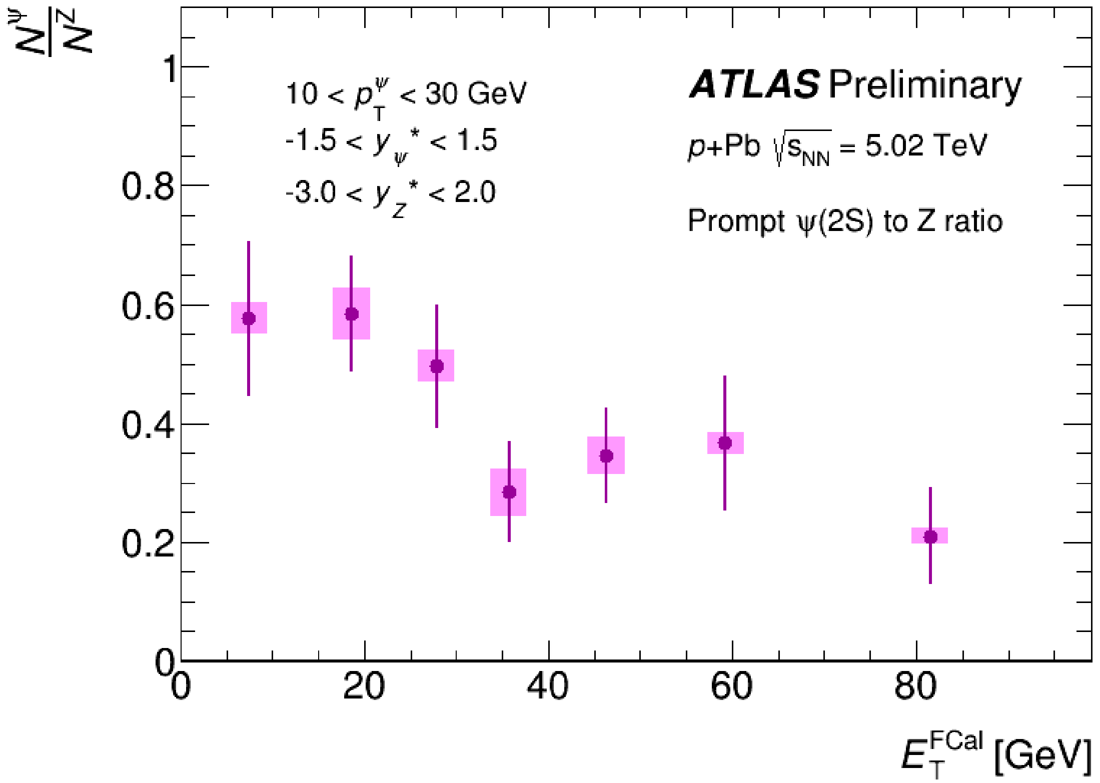
Flat ratio, suggest no strong modification

J/ψ from *b* to Z ratio vs multiplicity



Flat ratio, suggest no strong modification

Prompt $\psi(2S)$ to Z ratio vs multiplicity



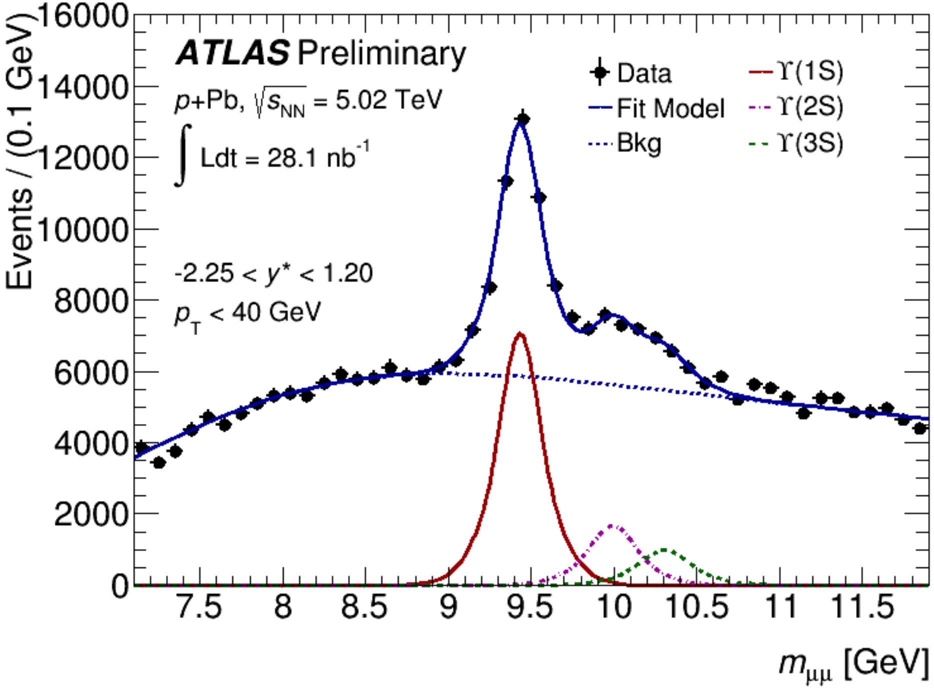
Hint of suppression at high multiplicities

ATLAS NOTE

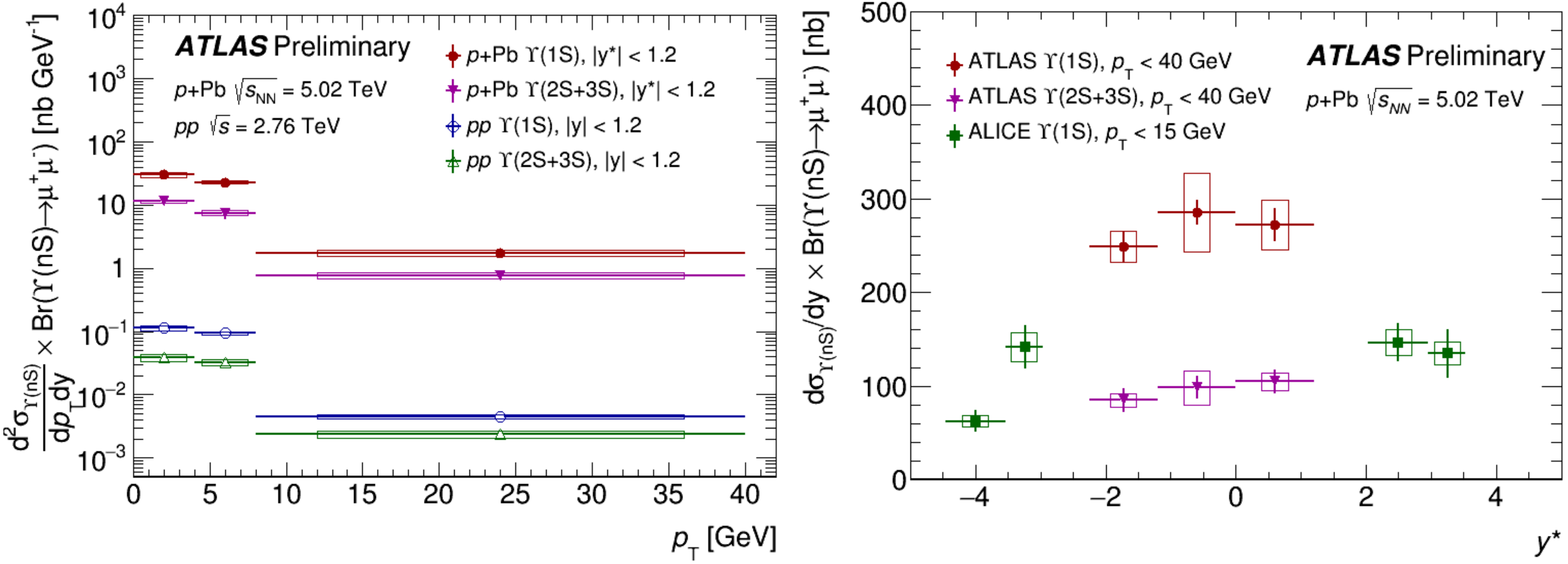
ATLAS-CONF-2015-050

Measurement of ϒ(nS) production with p+Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV and pp collisions at $\sqrt{s}$ = 2.76 TeV

$$\Upsilon(nS)$$



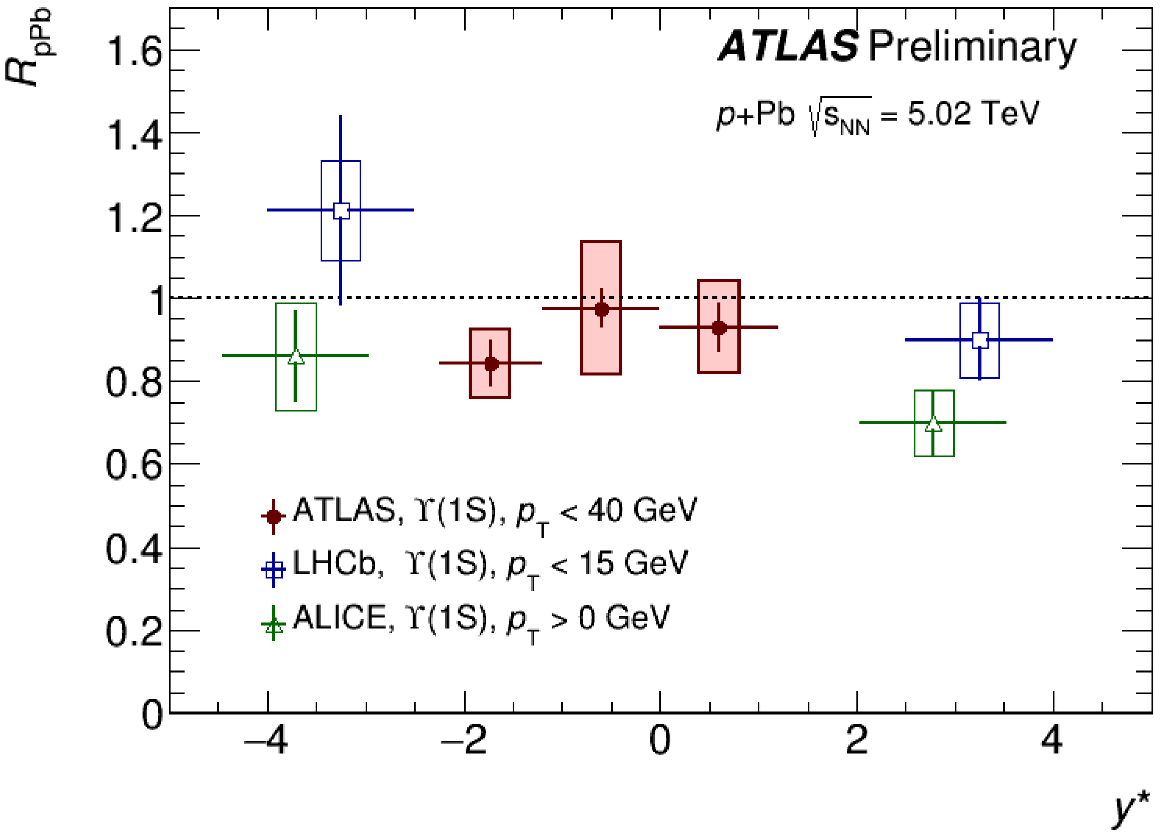
$\Upsilon(nS)$ Differential cross-sections



- Larger mass allows us to measure down to pT = 0
- We combine cross-sections for excited states

$\Upsilon(1S)$

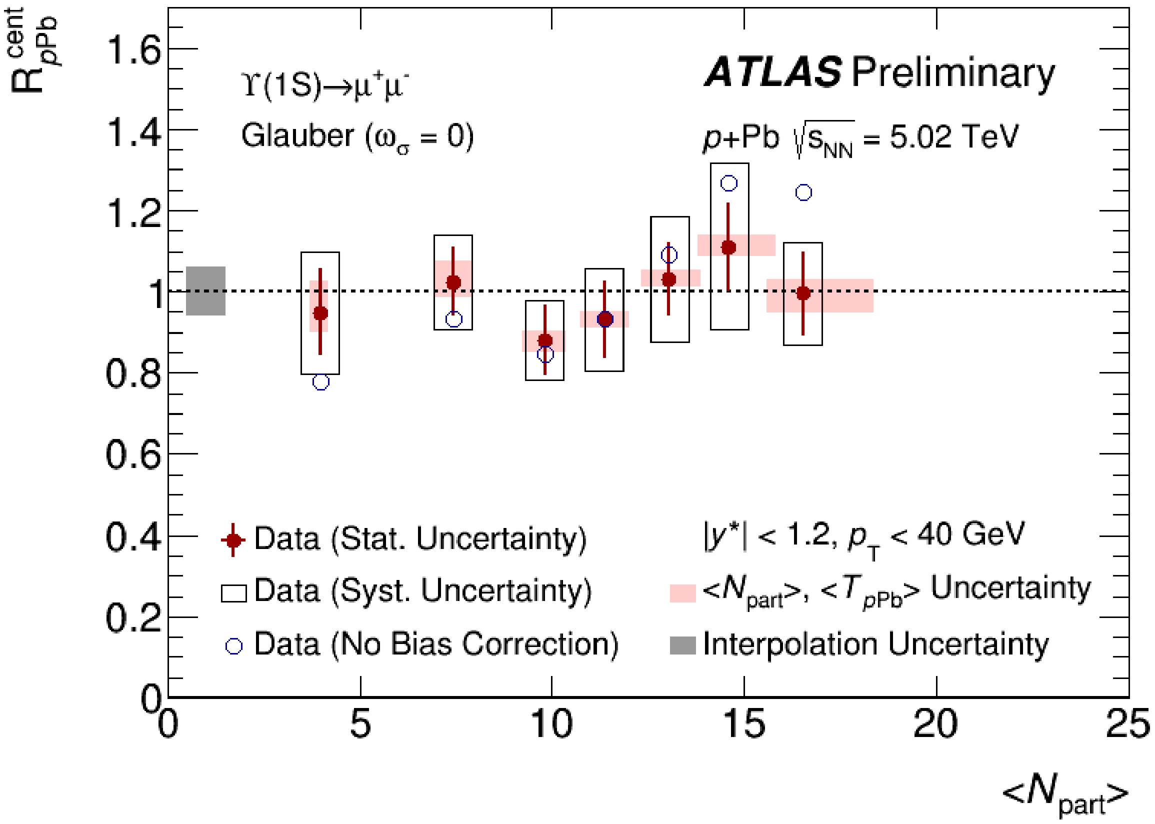
$$R_{pPb} = \frac{1}{A^{Pb}} \frac{d^2\sigma_{\psi}^{p+Pb}/dy^* dp_T}{d^2\sigma_{\psi}^{pp}/dy dp_T}$$



- **Consistent with unity, no strong kinematic dependence**

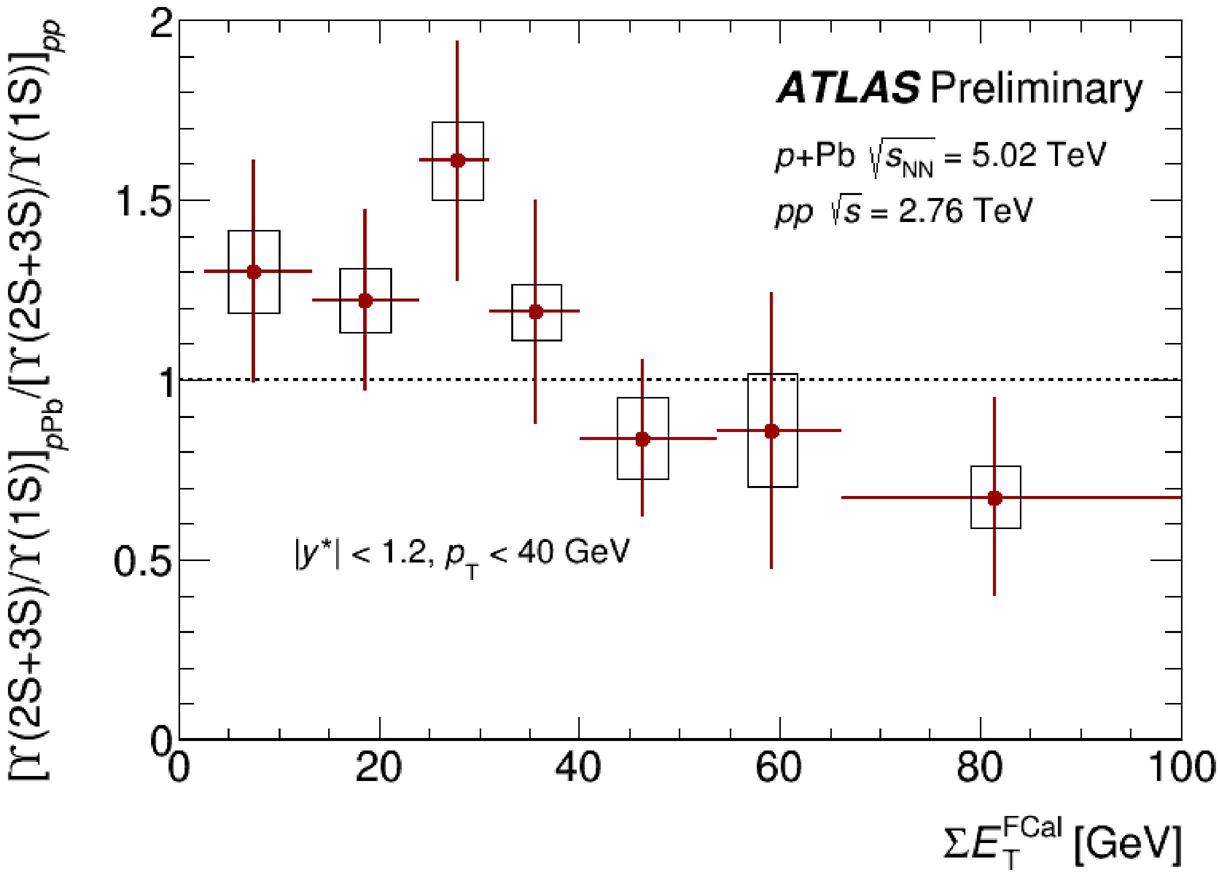
$\Upsilon(1S)$

$$R_{p\mathrm{Pb}} = \frac{1}{\langle T_{p\mathrm{Pb}} \rangle_{\mathrm{cent}}} \frac{1/N_{\mathrm{evt}}\, d^2 N_{\psi}^{p+\mathrm{Pb}}/dy^* dp_{\mathrm{T}} \big|_{\mathrm{cent}}}{d^2\sigma_{\psi}^{pp}/dy\, dp_{\mathrm{T}}}$$



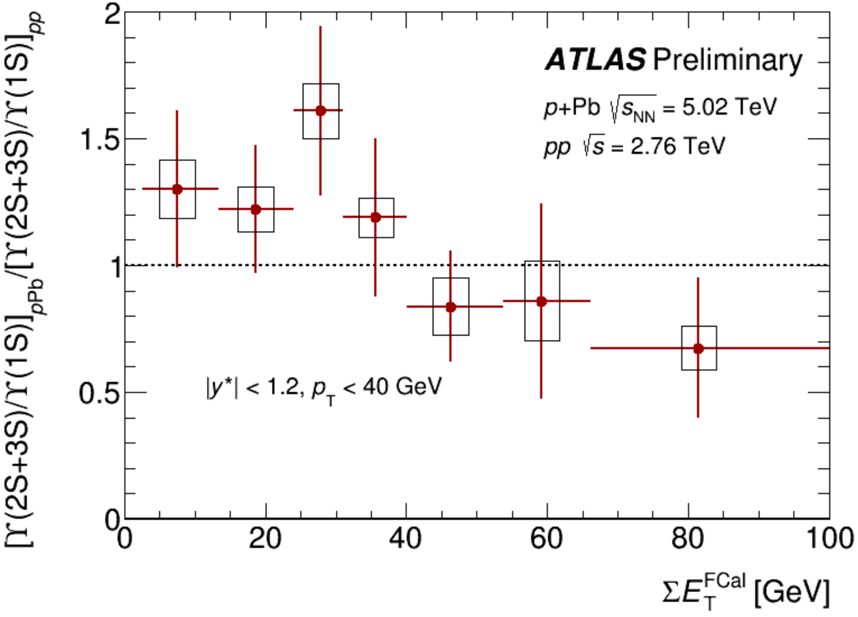
- **After centrality bias correction, flat and consistent with unity**

Double Ratio vs multiplicity

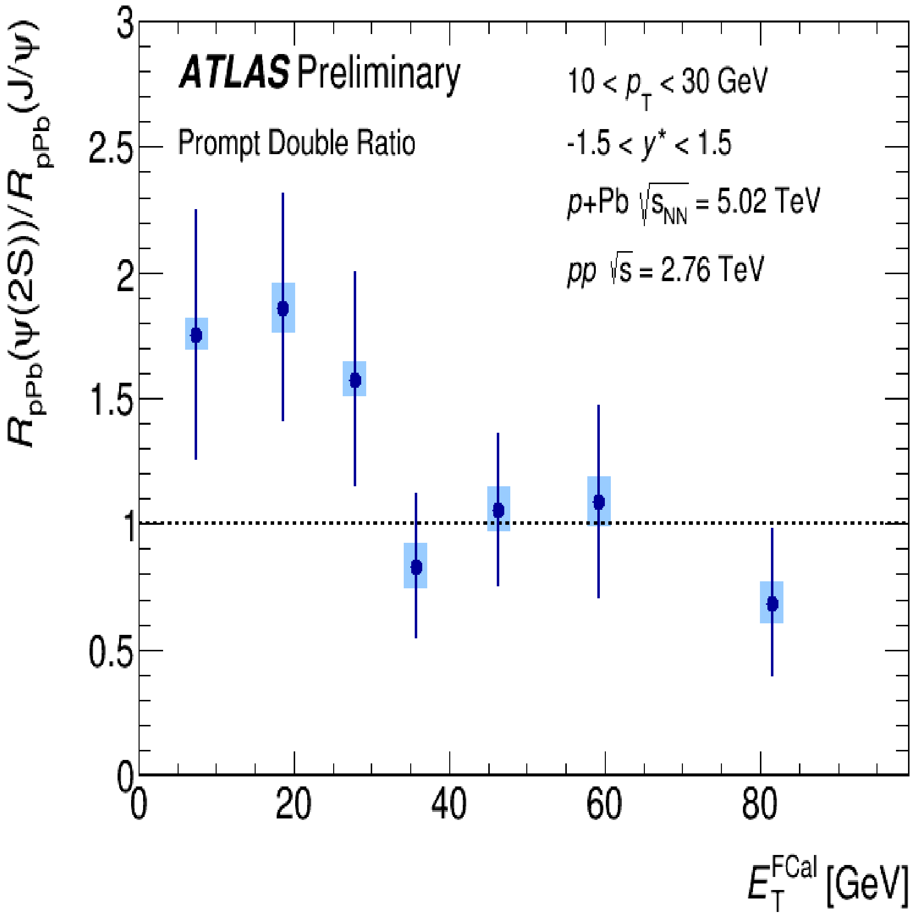


- Double ratio cancels any modification that is common to excited and ground states
- **Hint of centrality dependence, excited states more suppressed.**

- **Double ratio cancels any modification that is common to excited and ground states**



Bottomonia



Charmonia

Conclusions

ATLAS has started to produce quarkonia data in pA and pp collisions

J/ψ , $\psi(2S)$ and $b\bar{b} \rightarrow J/\psi + X$

Do now show strong kinematic modification wrt to pp ref

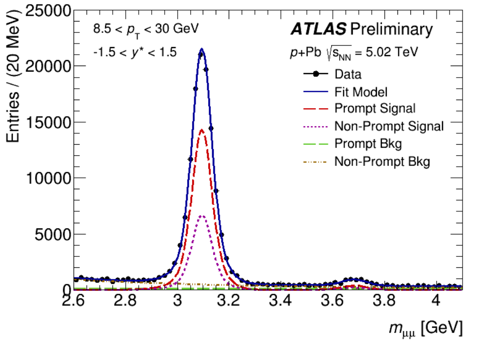
Hints of multiplicity dependence of excited to ground ratio

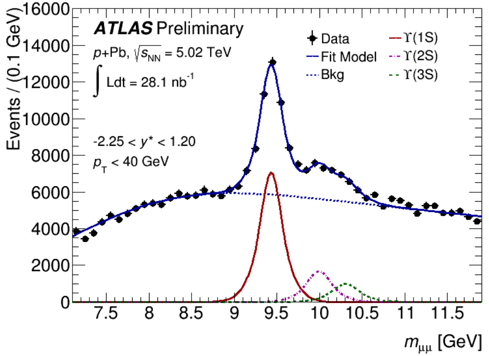
$\Upsilon(nS)$

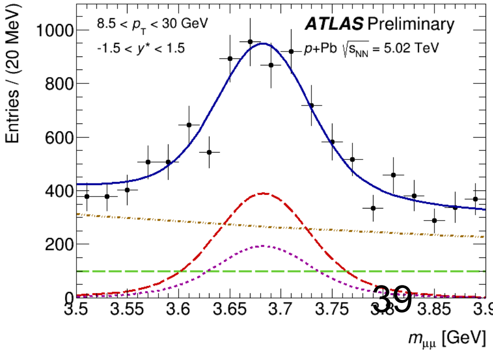
Do now show strong kinematic modification wrt to pp ref

Hints of multiplicity dependence of excited to ground ratio

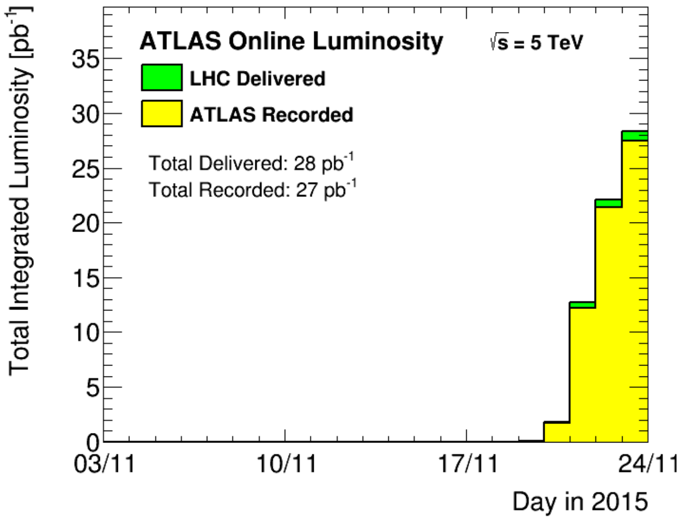
Stay tuned: ***https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults***

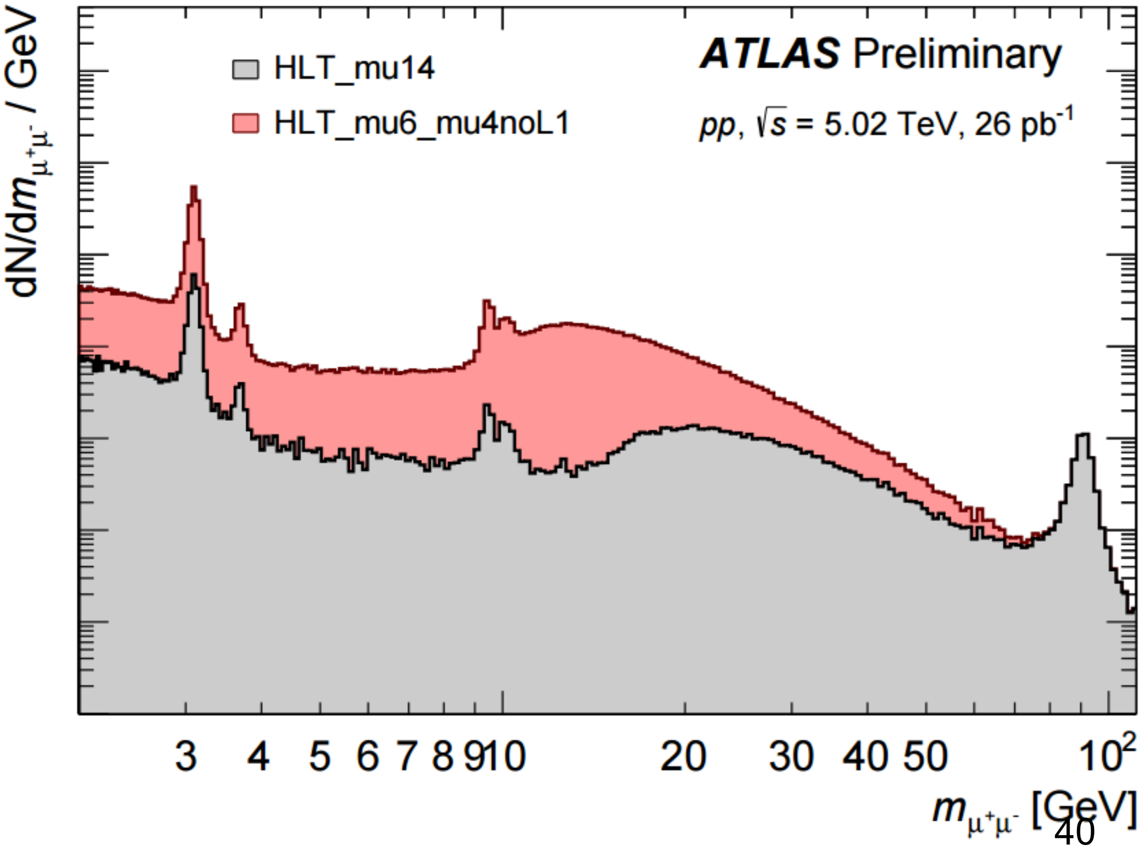






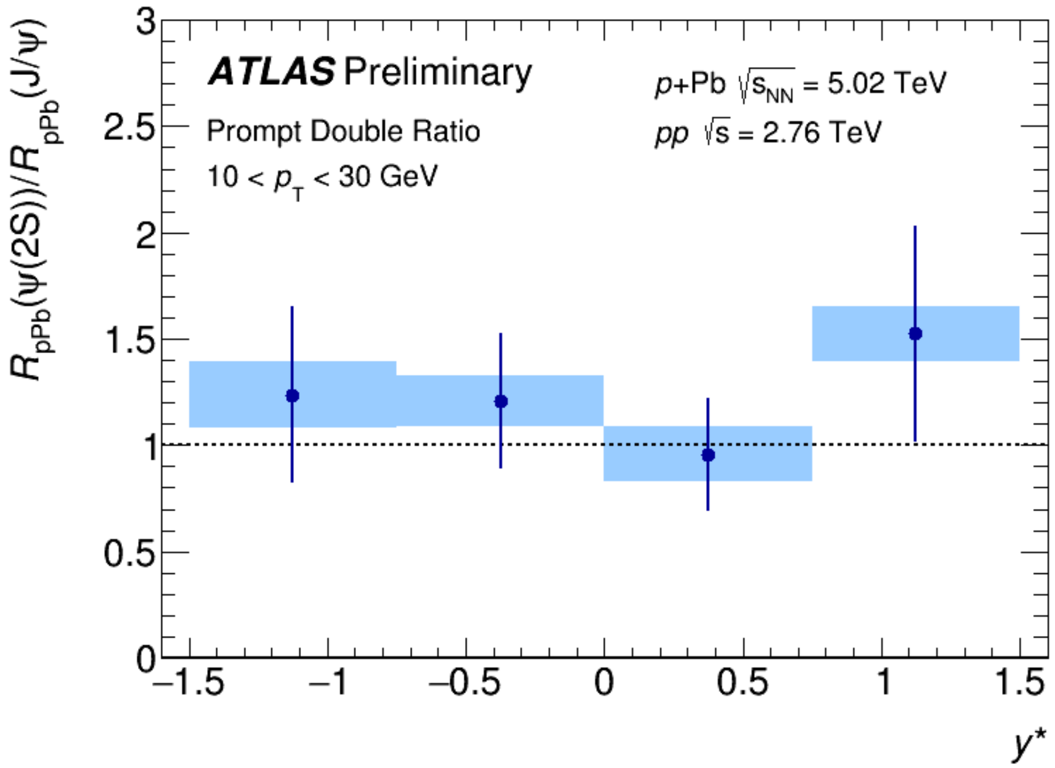
Looking forward for update results with 5 TeV pp data!





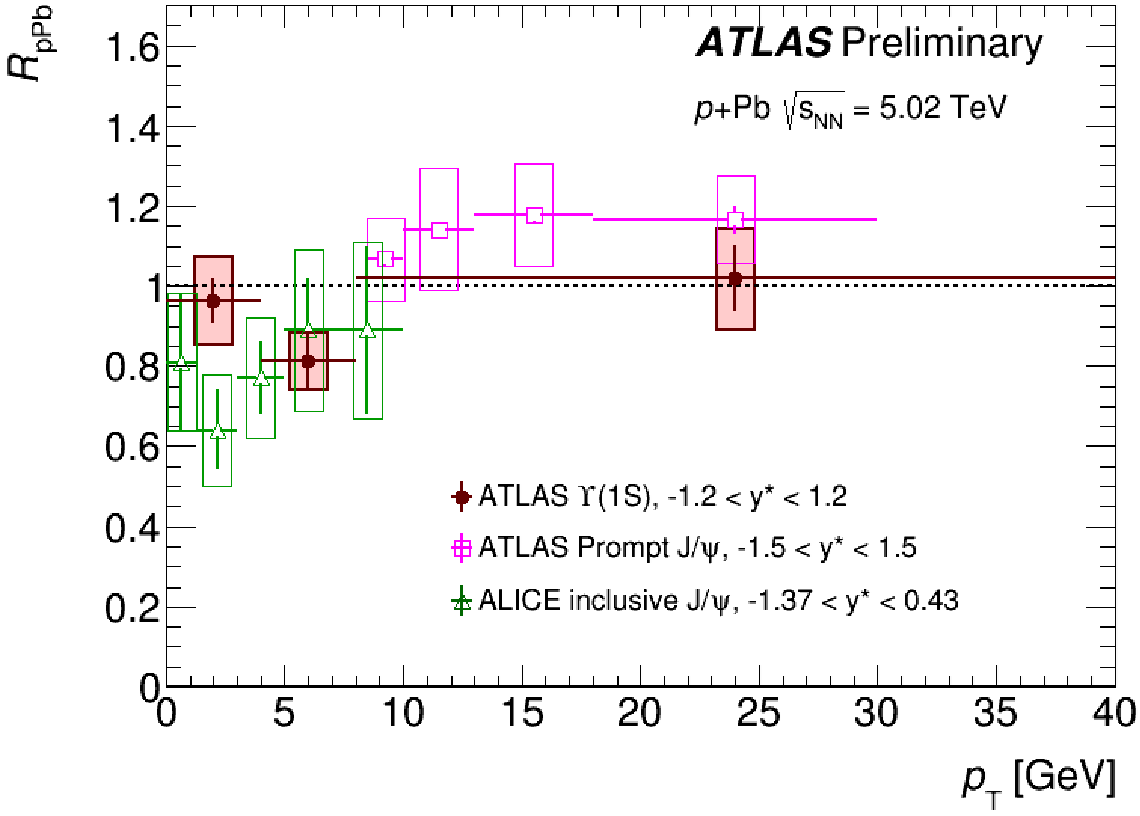
BACKUP SLIDES

Double ratio vs multiplicity

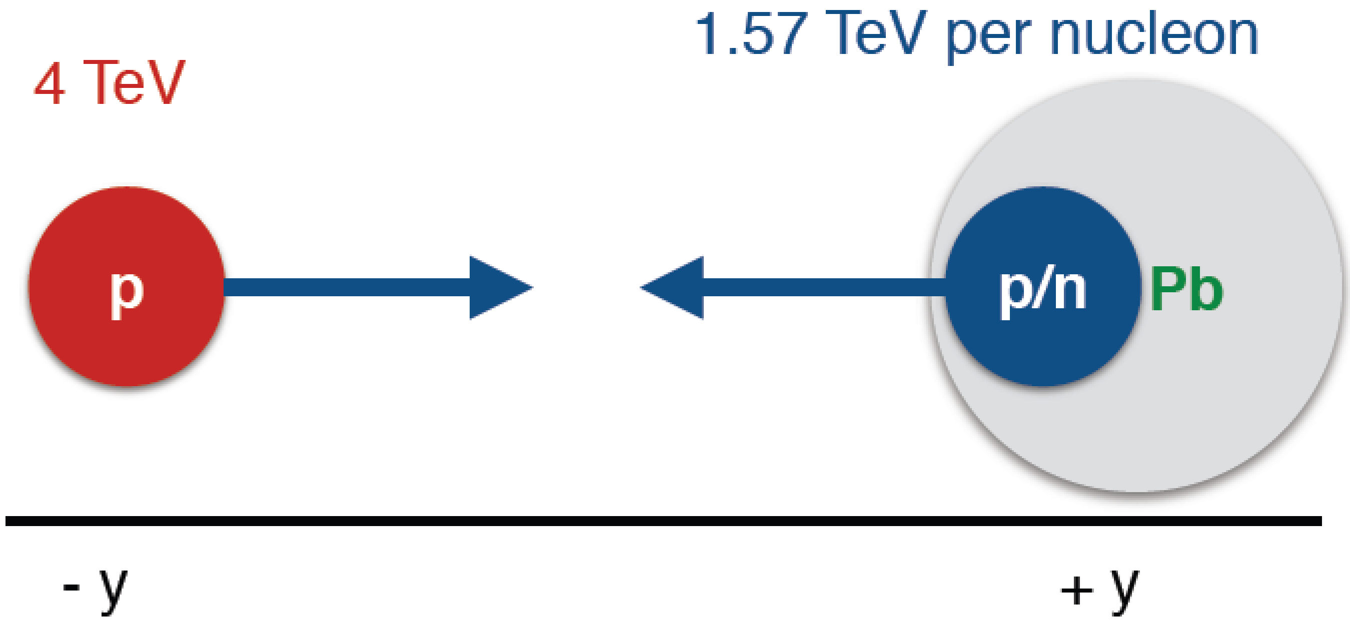


No strong rapidity dependence

$\Upsilon(1S)$

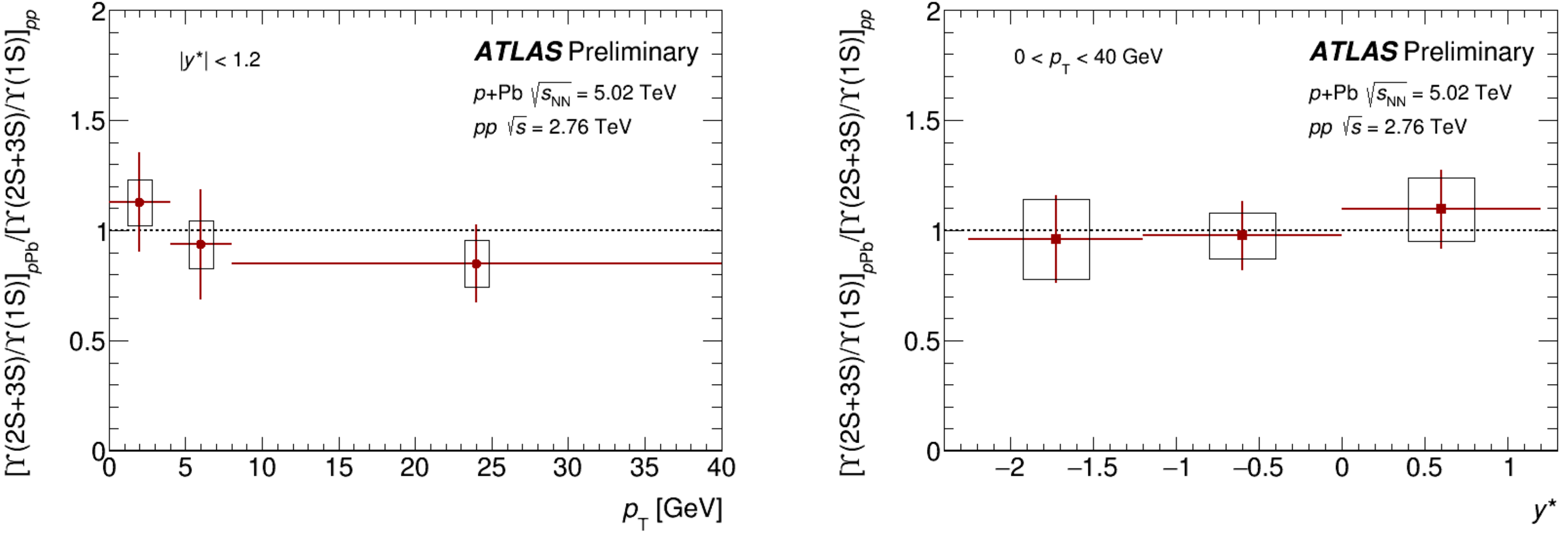


R_{pPb}
ATLAS Preliminary
p+Pb $\sqrt{s_{NN}}$ = 5.02 TeV
ATLAS Υ(1S), -1.2 < y* < 1.2
ATLAS Prompt J/ψ, -1.5 < y* < 1.5
ALICE inclusive J/ψ, -1.37 < y* < 0.43
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
0
5
10
15
20
25
30
35
40
p_T [GeV]



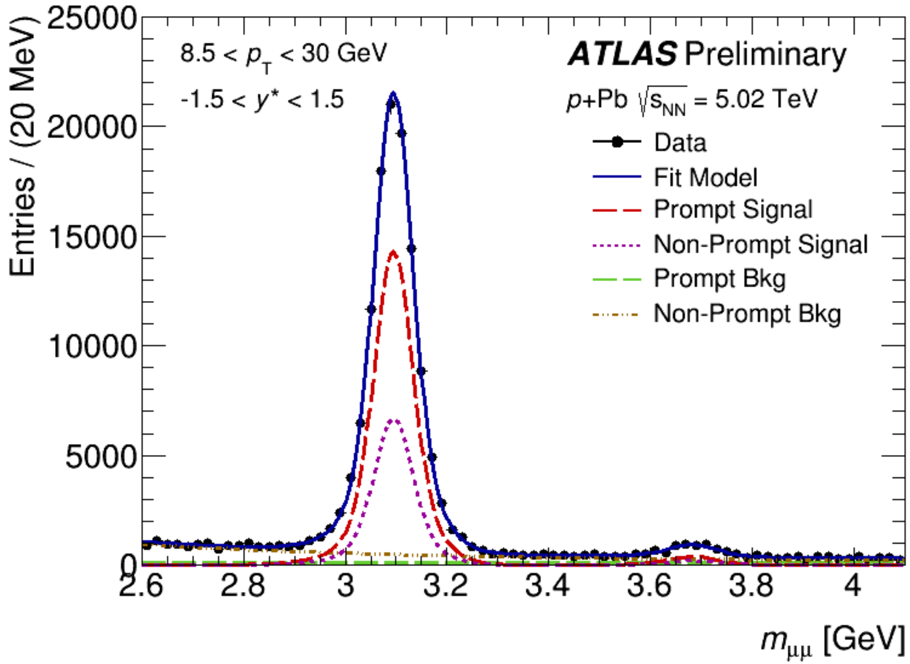
p+Pb collision beam configuration

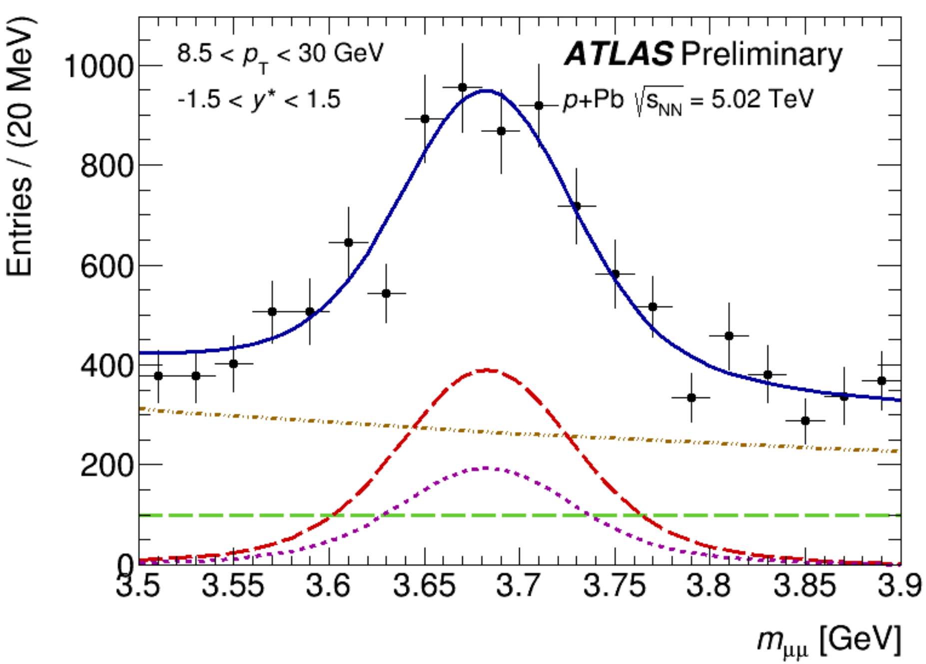
Double Ratio



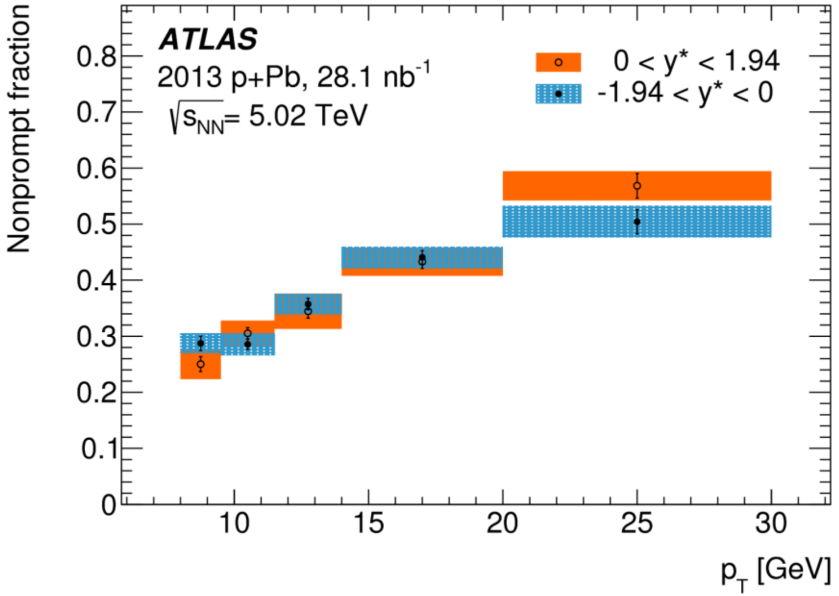
No strong kinematic dependence

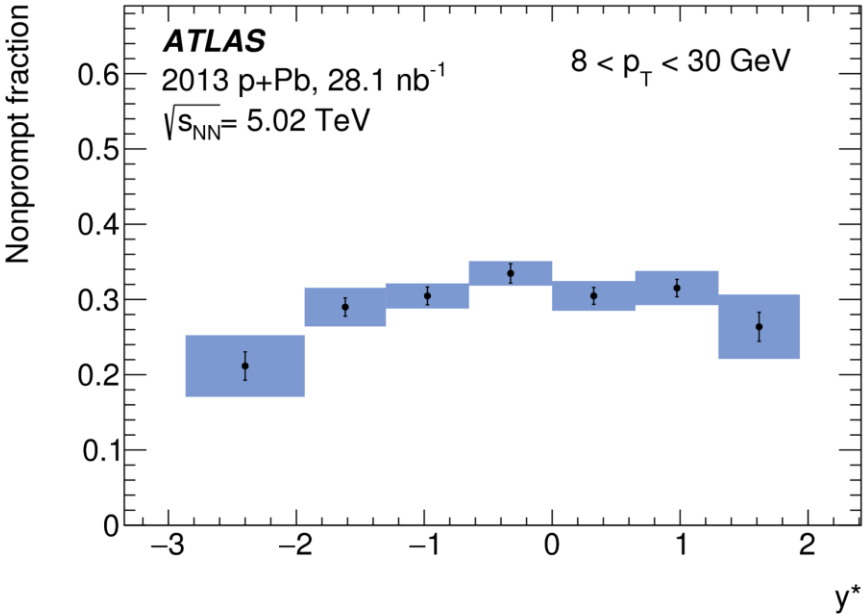
Signal extraction , $\psi(2S)$ included





Fraction of J/psi from b-hadrons

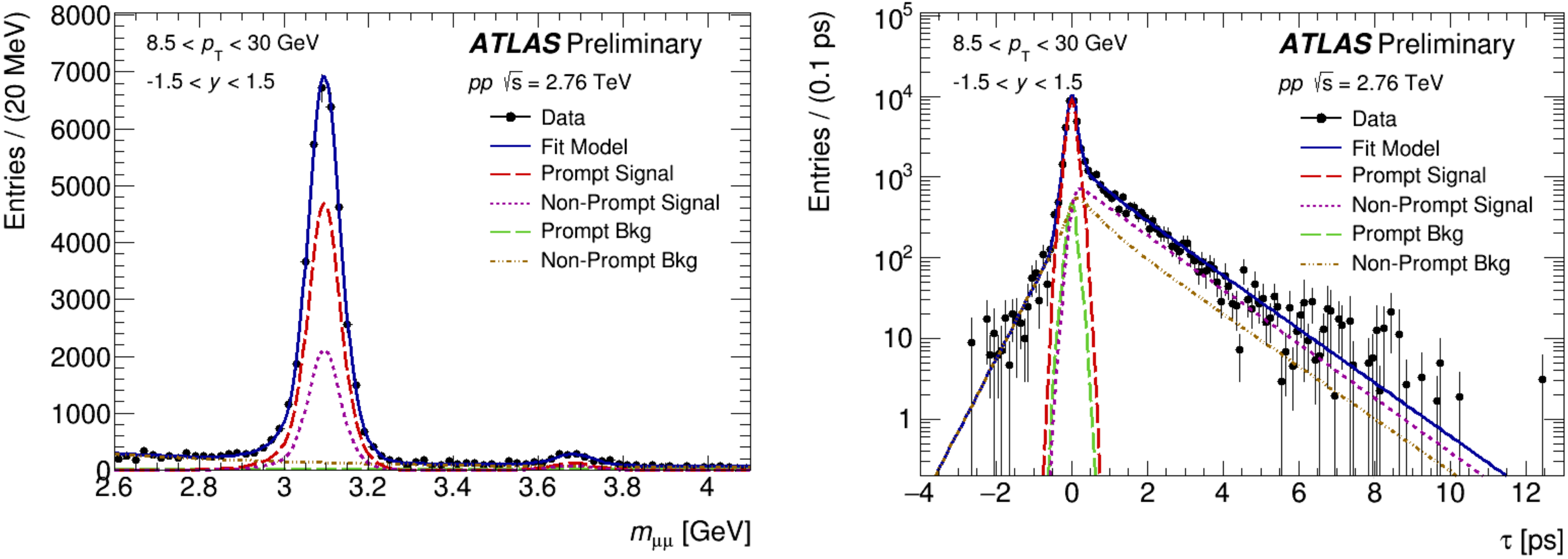




Increases with transverse momentum, from 25% to 50%

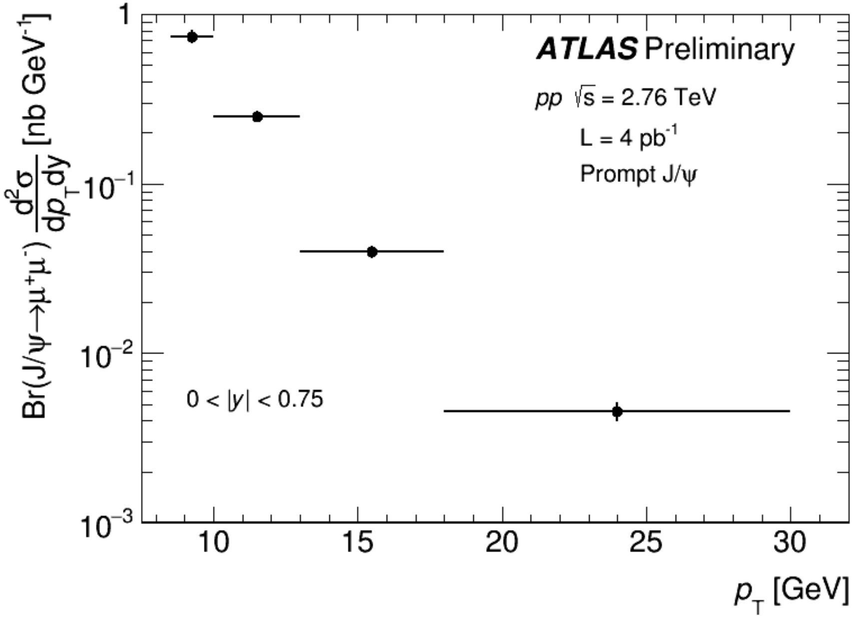
No strong rapidity dependence, flat about 30%

Signal extraction, pp @ 2.76 TeV

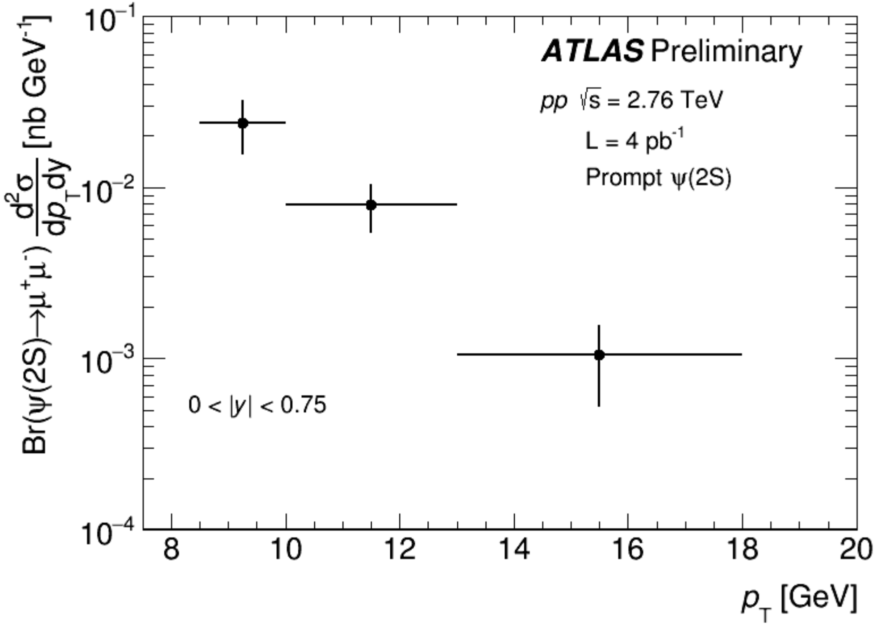


- More sophisticated fit model , but idea is the same as previous analysis
- Get fraction from b-decay in both psi(2s) and J/psi case

Differential cross-section, pp 2.76 TeV

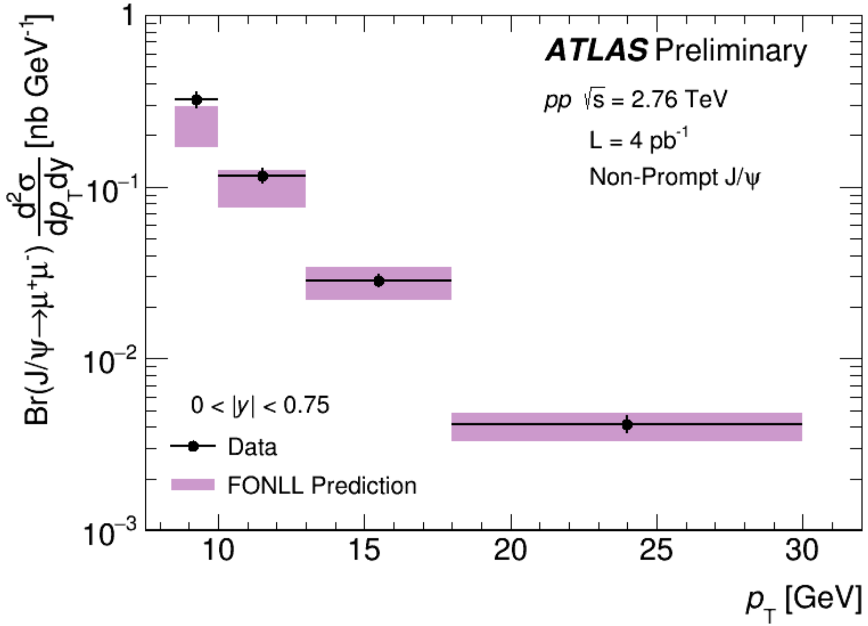


Prompt J/ψ

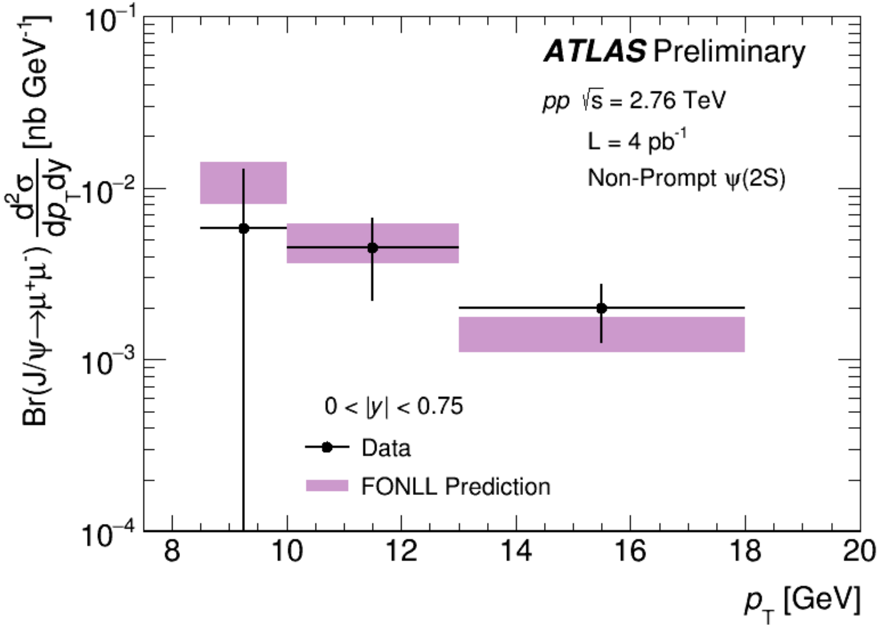


Prompt $\psi(2S)$

Differential cross-section, pp 2.76 TeV



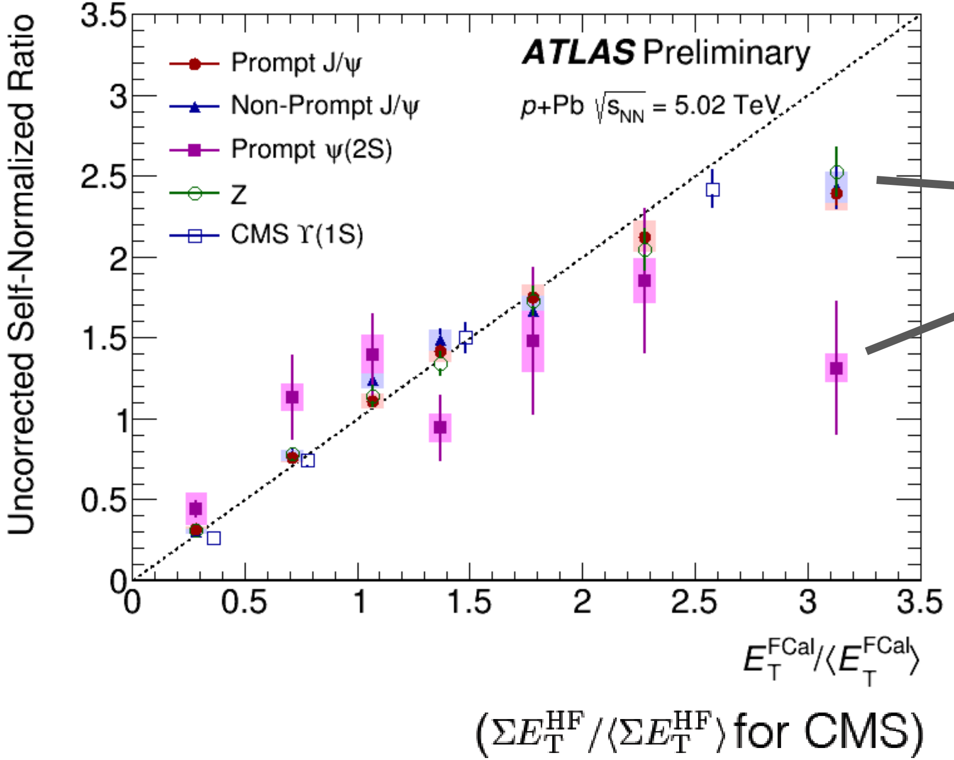
J/ψ from b



$\psi(2S)$ from b

Self-normalized ratio

$$\frac{\psi}{\langle\psi\rangle} = \frac{N_\psi / N_{\mathrm{evt}} \,|\, \mathrm{cent}}{N_\psi^{0-90\%} / N_{\mathrm{evt}}^{0-90\%}}$$



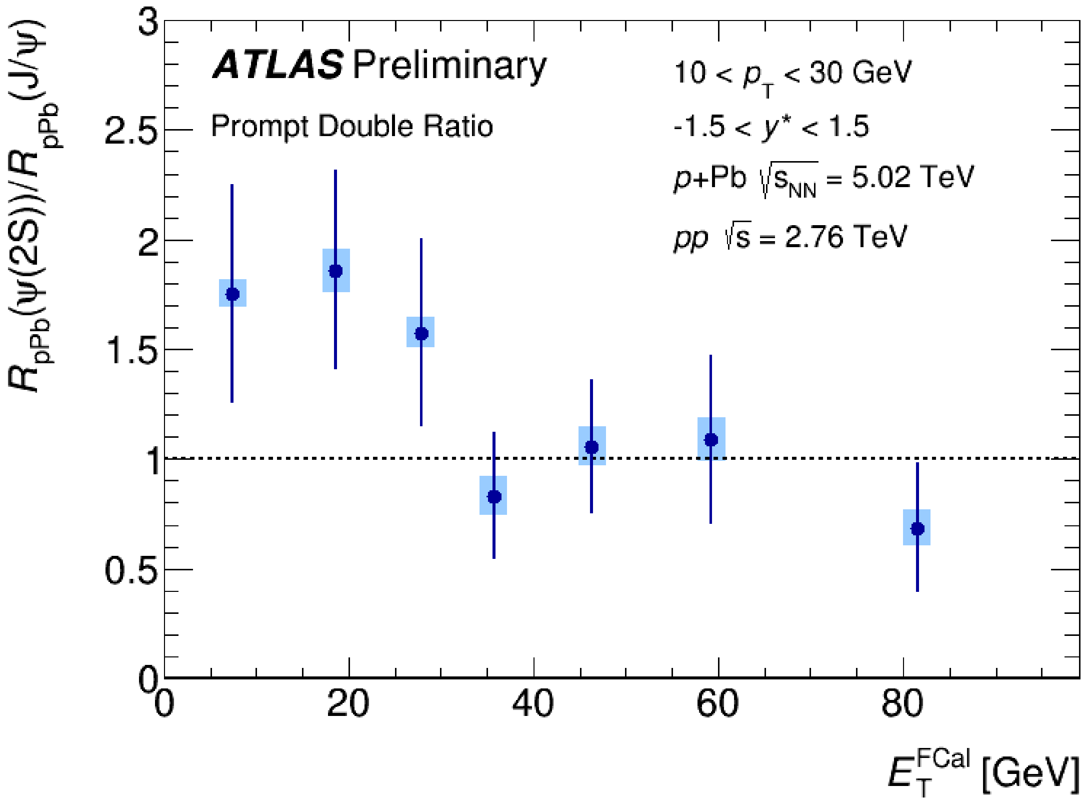
Hint of non-linearity at high multiplicities

$$\frac{\Sigma E_T^{\mathrm{FCal},cen}}{\langle \Sigma E_T^{\mathrm{FCal}} \rangle^{0-90\%}}$$

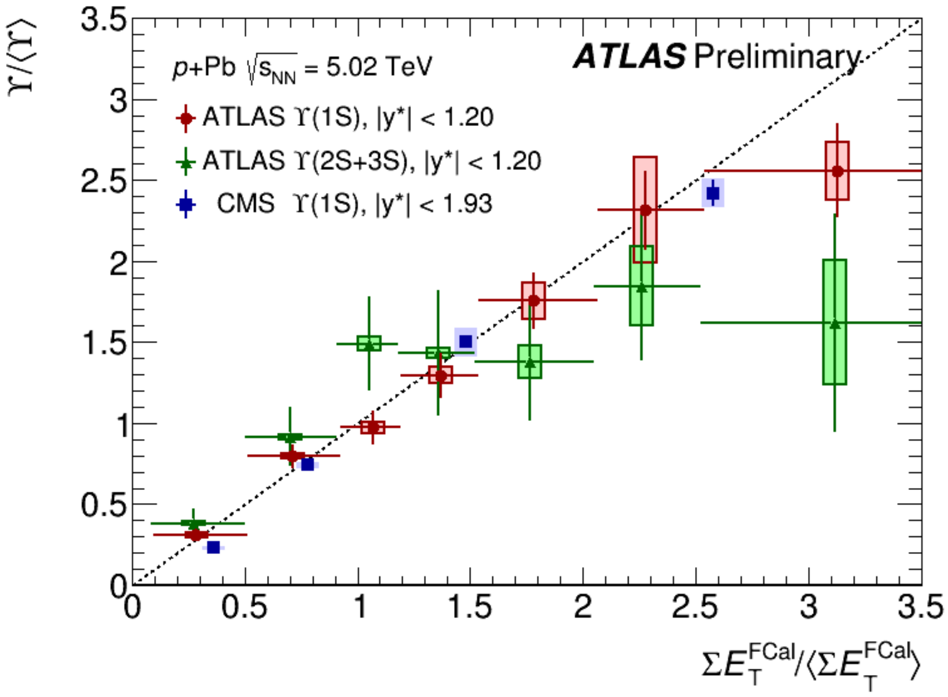
Obtained from MinBias events

Obtained from MinBias events

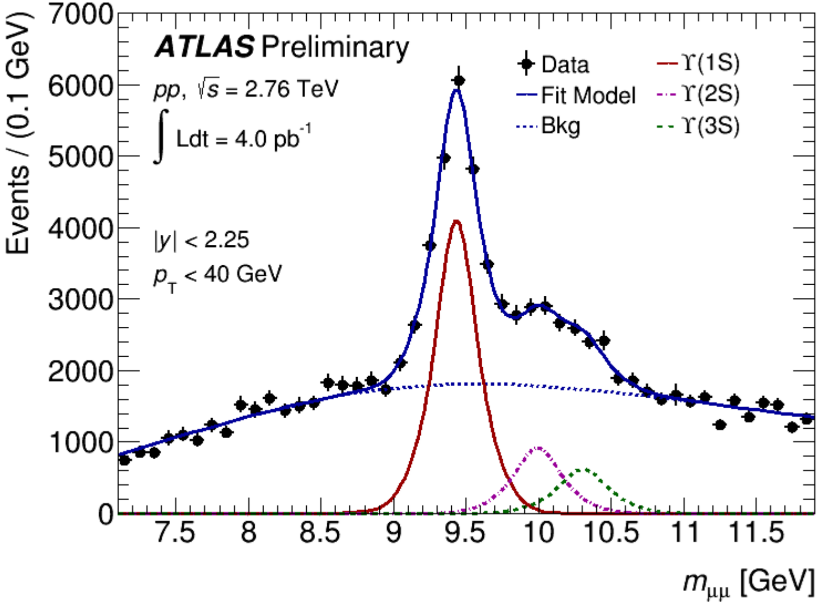
Double ratio vs multiplicity



(hint of) More suppression for psi(2S) at higher multiplicities

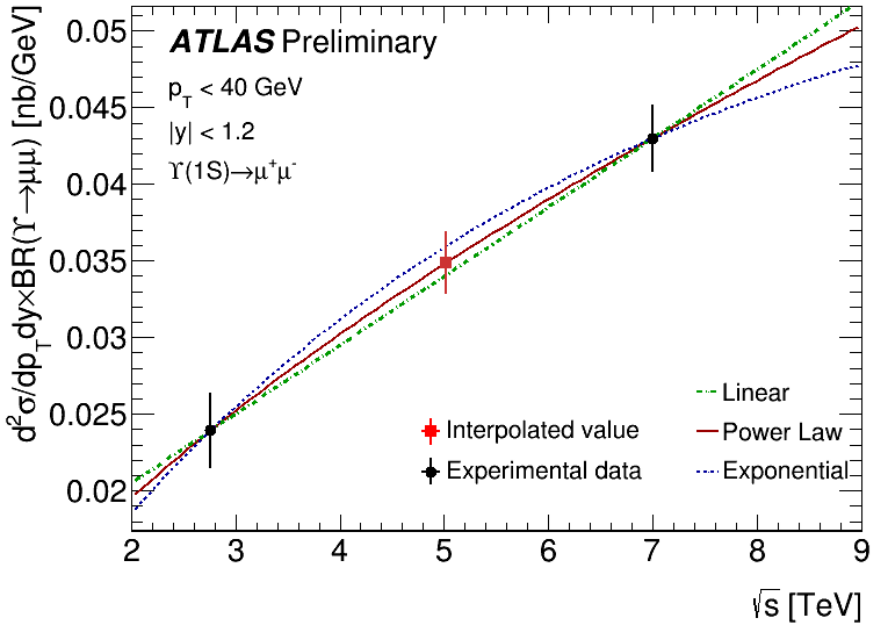


$\Upsilon/\langle\Upsilon\rangle$
p+Pb $\sqrt{s_{NN}}$ = 5.02 TeV
ATLAS Preliminary
ATLAS Υ(1S), |y*| < 1.20
ATLAS Υ(2S+3S), |y*| < 1.20
CMS Υ(1S), |y*| < 1.93
$\Sigma E_T^{FCal}/\langle\Sigma E_T^{FCal}\rangle$
0
0.5
1
1.5
2
2.5
3
3.5



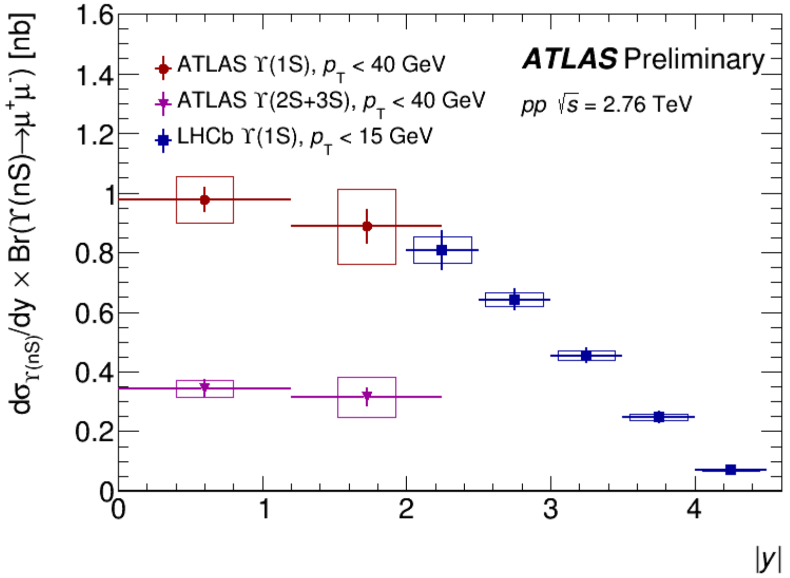
ATLAS Preliminary
pp, $\sqrt{s}$ = 2.76 TeV
$\int$ Ldt = 4.0 pb^{-1}
|y| < 2.25
p_T < 40 GeV
Data
Fit Model
Bkg
Υ(1S)
Υ(2S)
Υ(3S)
Events / (0.1 GeV)
$m_{\mu\mu}$ [GeV]
0
1000
2000
3000
4000
5000
6000
7000
7.5
8
8.5
9
9.5
10
10.5
11
11.5

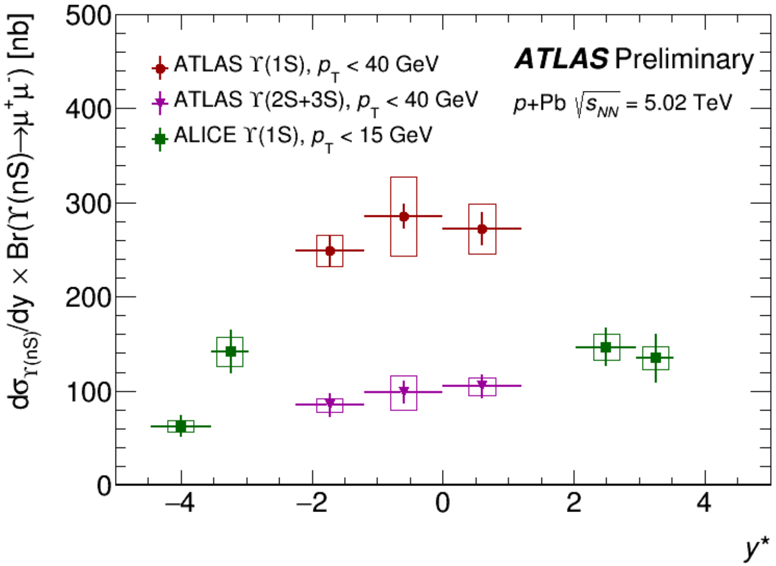
Interpolation to 5.02 TeV



Measured cross-section at 2.76 and 7 TeV used to estimate value at 5.02 TeV

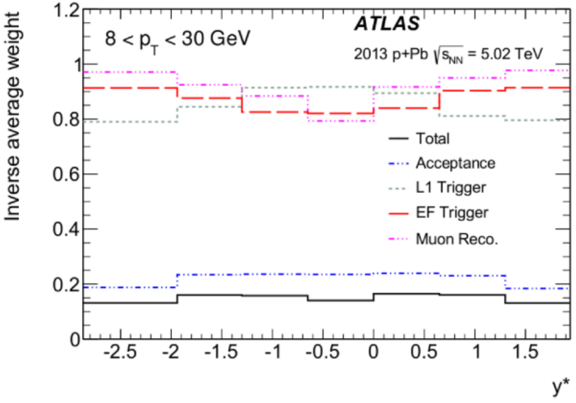
Differential cross-sections

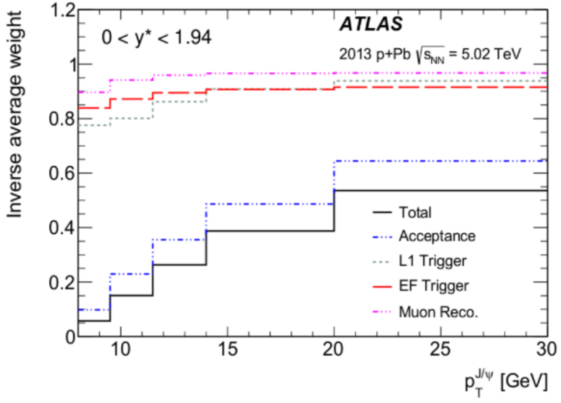


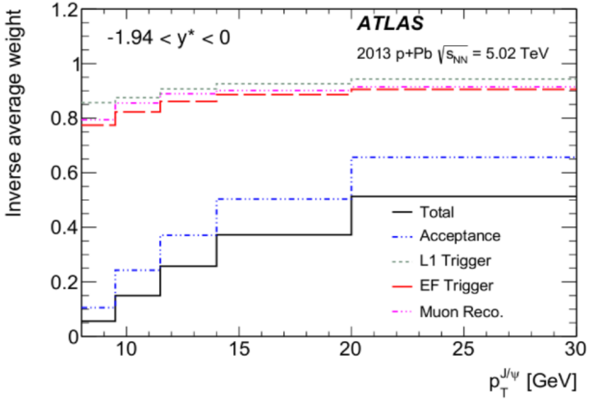


- Complementary to ALICE/LHCb results

Average corrections for J/psi







Driven by acceptance correction.

Flat in rapidity, but strong transverse momentum dependence

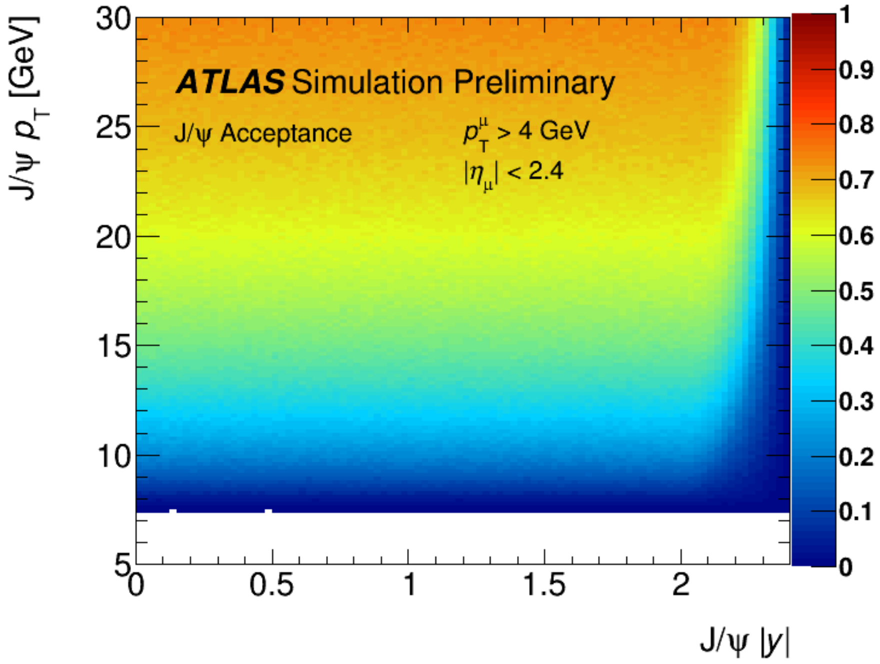
Acceptance correction

Fraction of simulated J/psi events that fall with muons in fiducial acceptance

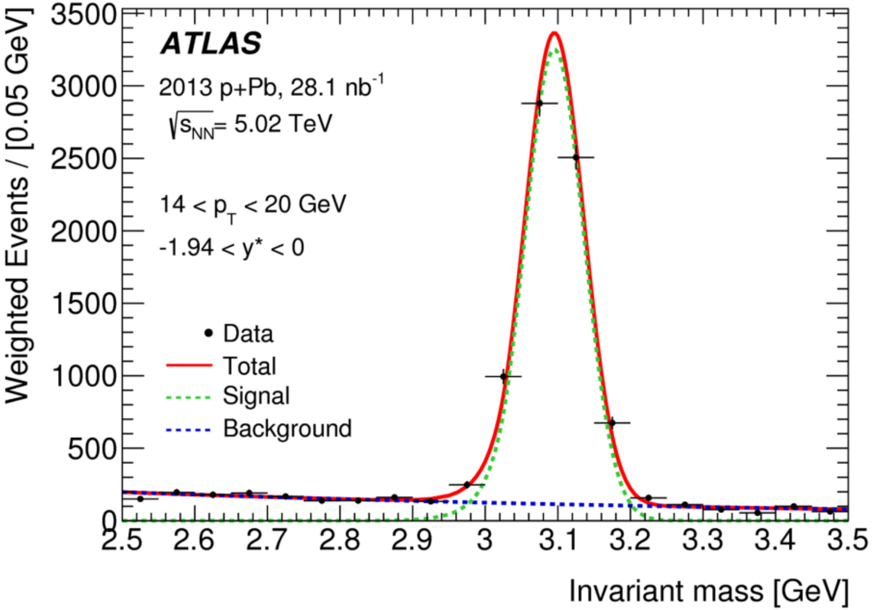
Purely geometric correction. (no detector effects)

Isotropic decay assumed (i.e, no polarization)

Requirement of muon pT > 4 GeV drives the acceptance loses



Signal extraction

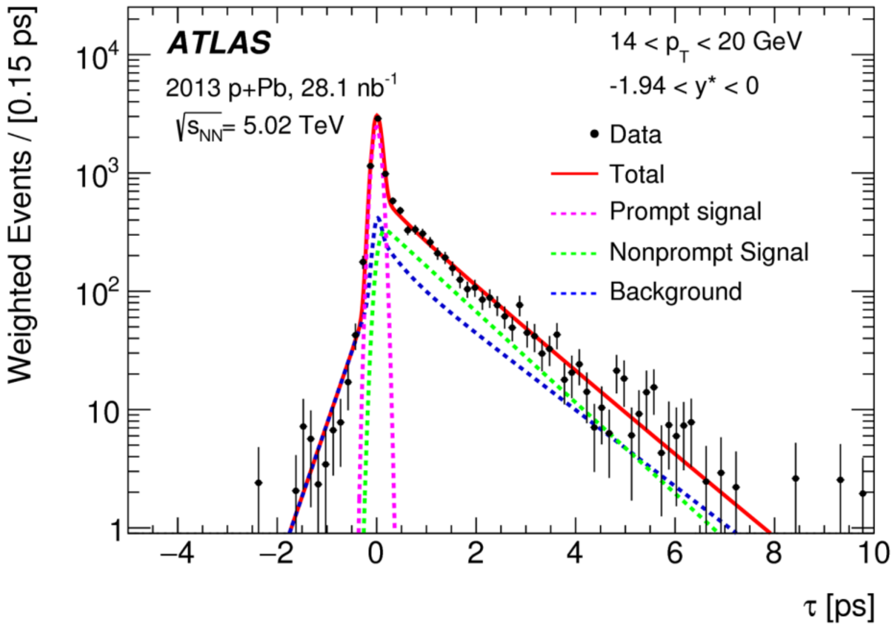


Clean signal

Low background level thanks to hermetic calorimeter system

Background, mostly from open heavy flavour decays, is modelled with a polynomial

Signal extraction



"Prompt J/psi"

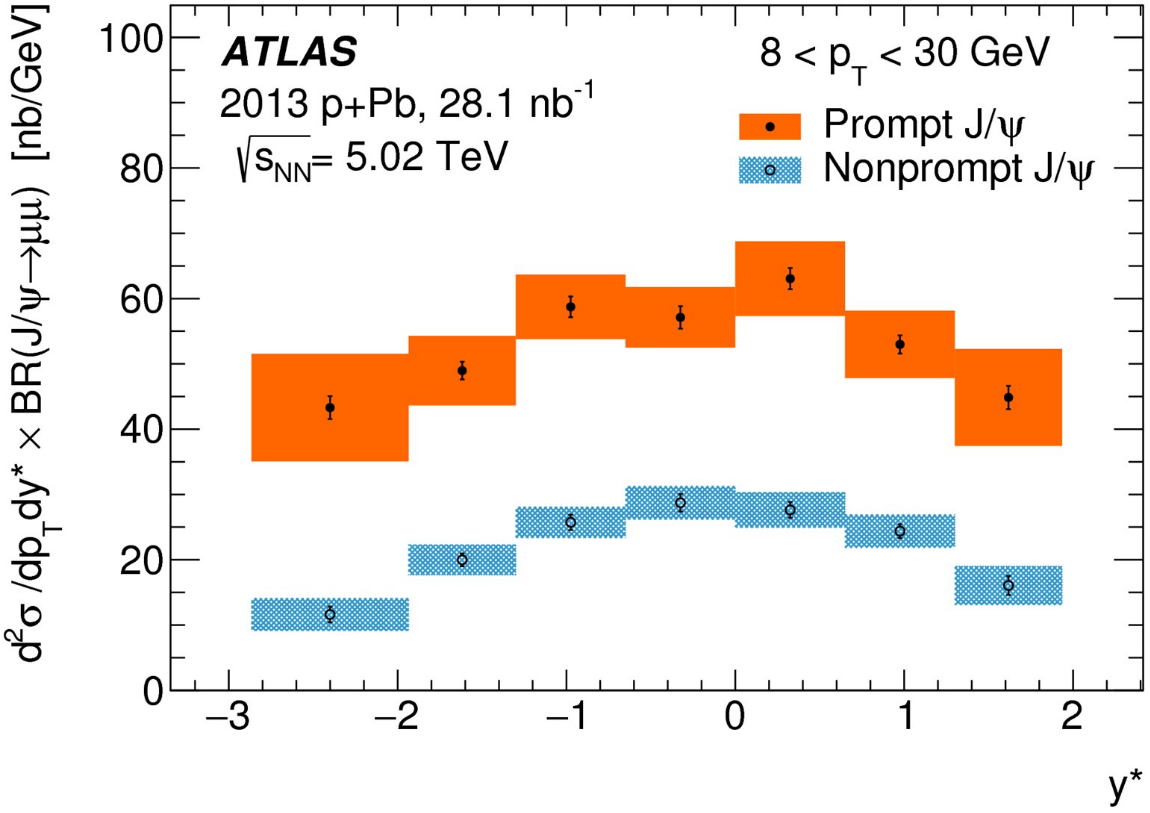
= directly produced, or decay from heavier charmonium states)

"Nonprompt J/psi"

= from B-hadron decays

Background shape extracted from sideband region.

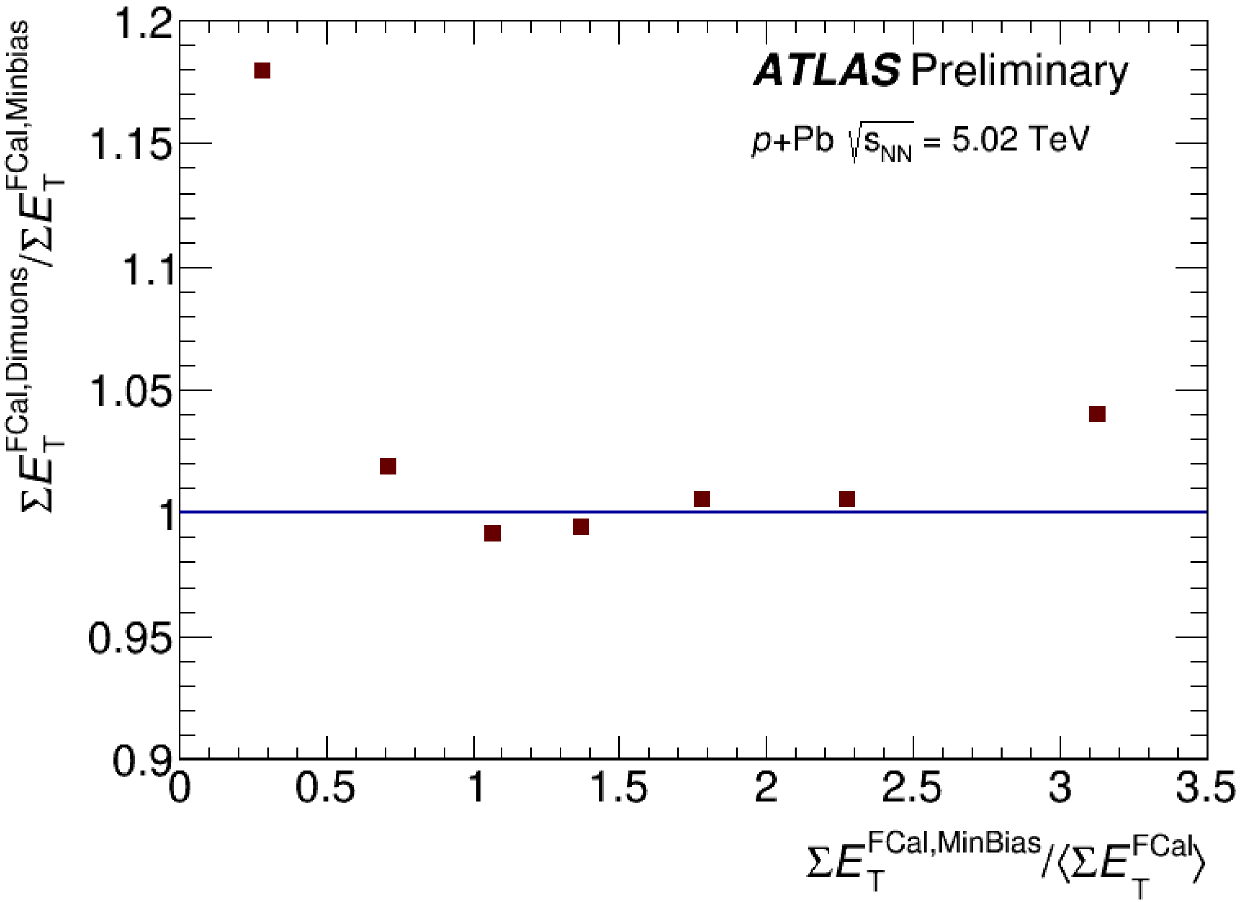
Differential cross-section vs rapidity



Fit model

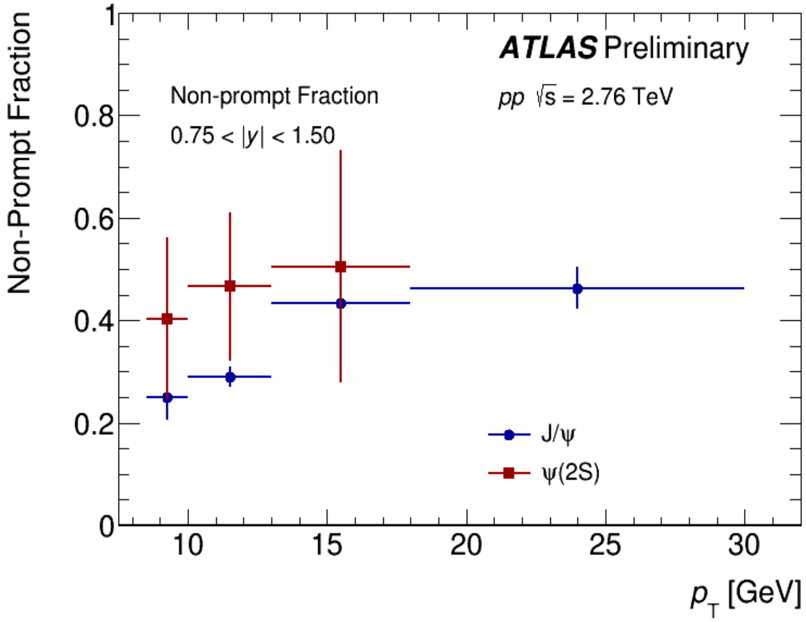
i	Type	Source	$f_i(m)$	$h_i(\tau)$
1	J/ψ S	P	$\omega_i CB_1(m) + (1-\omega_i)G_1(m)$	$\delta(\tau)$
2	J/ψ S	NP	$\omega_i CB_1(m) + (1-\omega_i)G_1(m)$	$E_1(\tau)$
3	$\psi(2S)$ S	P	$\omega_i CB_2(m) + (1-\omega_i)G_2(m)$	$\delta(\tau)$
4	$\psi(2S)$ S	NP	$\omega_i CB_2(m) + (1-\omega_i)G_2(m)$	$E_2(\tau)$
5	Bkg	P	$flat$	$\delta(\tau)$
6	Bkg	NP	$E_3(m)$	$E_4(\tau)$
7	Bkg	NP	$E_5(m)$	$E_6(\|\tau\|)$

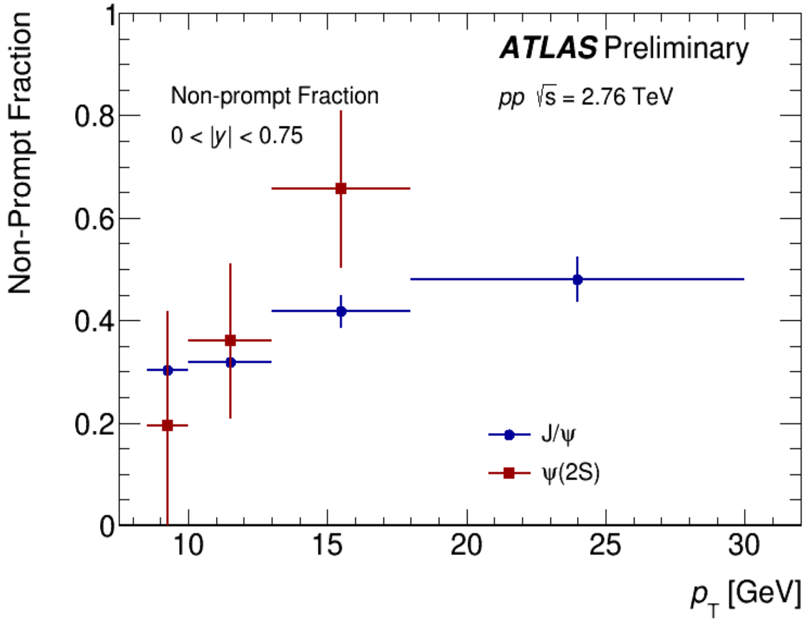
Table 2: Probability density functions for individual components in the fit model used to extract the prompt (P) and non-prompt (NP) contributions for the J/ψ and the $\psi(2S)$ signal (S) and background (Bkg). The index, i, runs from 1 to 7 for 7 different components. The composite pdf terms are defined as follows: CB - Crystal Ball; G - Gaussian; $E(\tau)$ - single sided exponential; $E(|\tau|)$ - double sided exponential; δ - delta function. The parameter ω is the fraction of CB function in the signal.

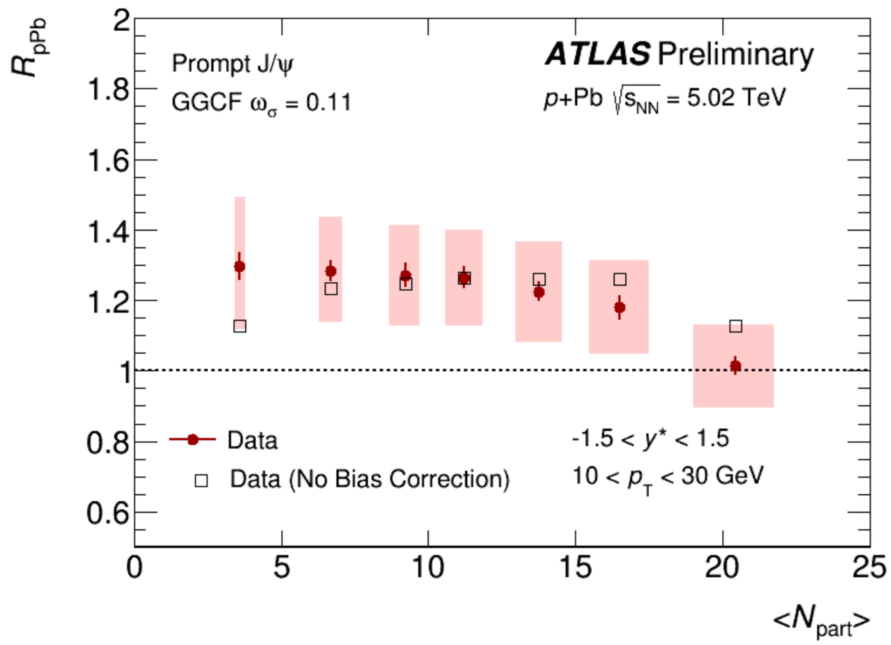


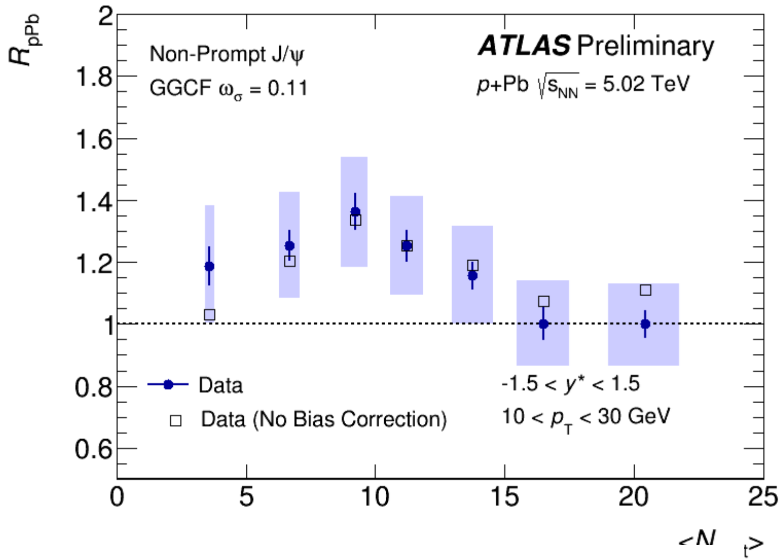
ATLAS Preliminary
p+Pb $\sqrt{s_{NN}}$ = 5.02 TeV
$\Sigma E_T^{FCal,Dimuons}/\Sigma E_T^{FCal,Minbias}$
$\Sigma E_T^{FCal,MinBias}/\langle\Sigma E_T^{FCal}\rangle$
1.2
1.15
1.1
1.05
1
0.95
0.9
0
0.5
1
1.5
2
2.5
3
3.5

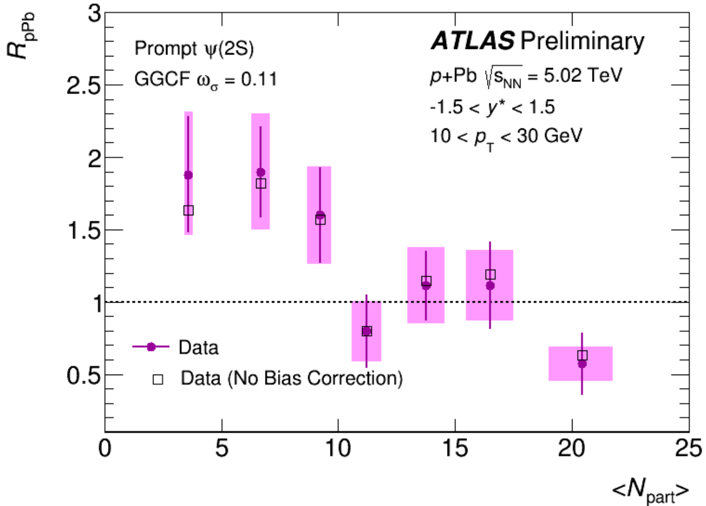
B-fractions pp 2.76 TeV data



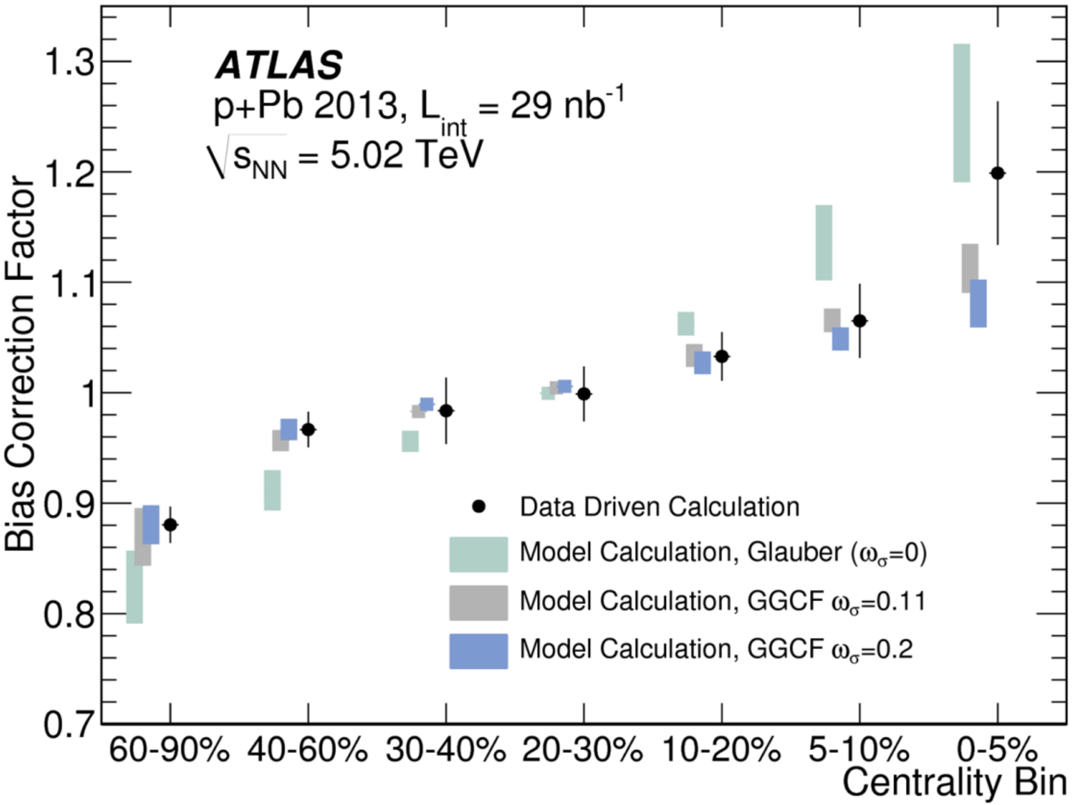



ATLAS Preliminary
Prompt J/ψ
GGCF ω_σ = 0.11
p+Pb √s_NN = 5.02 TeV
-1.5 < y* < 1.5
10 < p_T < 30 GeV
Data
Data (No Bias Correction)
R_pPb
<N_part>


ATLAS Preliminary
Non-Prompt J/ψ
GGCF ω_σ = 0.11
p+Pb √s_NN = 5.02 TeV
-1.5 < y* < 1.5
10 < p_T < 30 GeV
Data
Data (No Bias Correction)
R_pPb


ATLAS Preliminary
Prompt ψ(2S)
GGCF ω_σ = 0.11
p+Pb √s_NN = 5.02 TeV
-1.5 < y* < 1.5
10 < p_T < 30 GeV
Data
Data (No Bias Correction)
R_pPb
<N_part>

Centrality bias correction for p-Pb collisions



$\psi(2S)$ to J/ψ ratio vs multiplicity